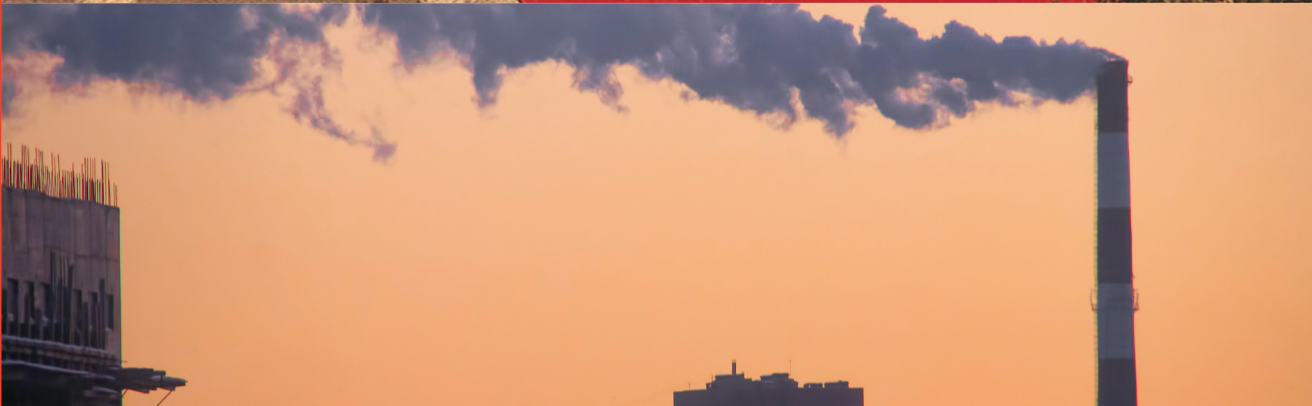




Natural and Human-Induced Hazards and Disasters in Africa

Genene Mulugeta and Thokozani Simelane (eds)

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Genene Mulugeta and
Thokozani Simelane (eds)

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Foreword

Drought, floods, extreme temperatures, cyclones and other hydro-meteorological events unfortunately play a major part in Africa's history and present situation. With a changing climate these factors are projected to worsen and have even more negative effects on Africans, their socio-economic situations and their ecosystems. Africa is also affected by geophysical hazards such as earthquakes and the eruptions of active volcanoes. The Millennium Development Goals for 2015 provide clear, quantifiable targets to be achieved in all countries but it is clear that development is retarded by the impacts of these hazardous events. According to the United Nations International Strategy for Disaster Reduction, *'The starting point for reducing disaster risk and for promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face, and of the ways in which hazards and vulnerabilities are changing in the short and long term'*. Reducing disaster risk requires an inherently multi-disciplinary approach – to the hazards and also to vulnerability and exposure. This knowledge needs to be specific to the region and society so that appropriate actions can be taken. This book examines hazards, both geophysical and hydro-meteorological, and their impacts from a multi-disciplinary approach.

In 2008, the International Council for Science (ICSU), together with the International Social Sciences Council (ISSC) and the United Nations International Strategy for Disaster Reduction (UNISDR), created the *Integrated Research on Disaster Risk (IRDR) Program: Addressing the challenge of natural and human-induced environmental hazards*. The scientific research approach of the IRDR Programme is international and multi-disciplinary. Its objectives are to: 1) characterise hazards, vulnerability and risk; 2) understand decision making in complex and changing risk contexts; and 3) reduce risk and curb losses through knowledge-based actions. Knowledge is needed of the ways in which hazards and vulnerabilities are changing. In this context, hazards are usually natural but the disasters that follow are not. A challenge for disaster risk reduction researchers is in advising communities and governments how to deal with hazards, vulnerabilities and exposure in the context of present knowledge and projections for the future. This book addresses that challenge and provides analyses of specific hazards and the measures and strategies that need to be taken to curb loss of life and property.

In 2012, the United Nations convened the Rio+20 Conference on the *'future we want'*. The final report calls for *'disaster risk reduction and the building of resilience*

to disasters to be addressed with a renewed sense of urgency ...' and the importance of: '*early warning systems*'; '*comprehensive hazard and risk assessments, and knowledge- and information- sharing*'; and '*stronger interlinkages among disaster risk reduction, recovery and long-term development planning*'. Recognising that unfortunately it is the poorest people who are most vulnerable and exposed, this book provides the basis for more effective disaster risk reduction efforts by placing them in the context of sustainable development and global environmental change and invites societies and their governments to take appropriate actions.

Gordon McBean

President: International Council for Science Union

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Abbreviations and Acronyms

AIDS	Acquired Immunodeficiency Syndrome
ANC	African National Congress
ATJ	Afar Triple Junction
AU	African Union
BCC	Beijing Climate Centre
CAPARO	Renewable Agriculture Developments
CMA	China Meteorological Administration
CO ₂	Carbon Dioxide
CPI	Central Pressure Index
CVL	Cameroon Volcanic Line
DRC	Democratic Republic of Congo
DRM	Disaster Risk Management
DRR	Disaster Reduction and Relief
DRR	Disaster Risk Research
EARS	East African Rift System
EC-JRC	European Commission Joint Research Centre
ENSO	El Niño Southern Oscillation
FCC	Faecal Coliform Count
FEWS	Famine Early Warning System
GAMA	Greater Accra Metropolitan Area
GDP	Gross Domestic Product
GHG	Green House Gases
GIEWS	Global Information and Early Warning Systems on Food and Agriculture
HDI	Human Development Index
HEWS	Humanitarian Early Warning Service
HFA	Hyogo Framework for Action
HIV	Human Immunodeficiency Virus
HUB	Hydrocarbon Utilising Bacteria
IDPs	Internally Displaced Persons
IPO	International Programme Office
IR	Infrared
ISC	International Seismological Centre
LIDAR	Light Detection and Ranging
MC	Mount Cameroon

MCCs	Mesoscale Convective Complexes
MDGs	Millennium Development Goals
MER	Main Ethiopian Rift
MMI	Mercalli Magnitude Intensity
MODIS	Moderate Resolution Imaging Spectroradiometer
MSM	Men having Sex with Men
NADMO	National Disaster Management Organisation
NDMP	National Disaster Management Plan
NGOs	Non-Governmental Organisations
NMDP	Nyos-Monoun Degassing Project
OL	Oldoinyo Lengai
OMI	Ozone Monitoring Instrument
OSL	Optically Stimulated Luminescence
PSHA	Probabilistic Seismic Hazards Assessment
QIH	Quifel International Holdings
SIDS	Small Island Developing States
SKVP	South Kivu Volcanic Province
SLA	Sierra Leone Agriculture
SLF	Sustainable Livelihoods Framework
SO ₂	Sulphur Dioxide
SSA	Sub-Saharan Africa
TBC	Total Bacterial Count
UN-HABITAT	United Nations Human Settlement Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nation's Framework Convention on Climate Change
UNFPA	United Nations Fund for Population Activities
UNICEF	United Nations Children's Fund
UNISDR	United Nations International Strategy for Disaster Reduction
USGS	United States Geological Survey
VVP	Virunga Volcanic Province
WASH	Water, Sanitation and Hygiene
WDR	World Disaster Report
WFP	World Food Programme
WHO	World Health Organization
WMO	World Meteorological Organisation
WWSSN	Worldwide Standard Seismograph Network

CHAPTER 1

Overview of the Impact of Hazards and Disasters in Africa

Genene Mulugeta

Introduction

This chapter presents an overview, at the regional level, of the major hazards that affect Africa. The information on victims and loss data have been extracted from the International Emergency Events Database (EM-DAT), maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the University of Louvain, Belgium.¹ In the database, natural hazards are categorised into five major sub-groups; these are further sub-divided into disaster types (shown in brackets), as follows: biological (epidemic, insect infestation); climatological (drought, extreme temperature, wildfire); hydrological (flood, mass movement – wet); meteorological (storm); and geophysical (earthquake, volcano, mass movement – dry). The database is compiled from various sources including UN agencies, non-governmental organisations, insurance companies, research institutions and press agencies. As the database is subject to regular updates, modifications occur in the recorded historical data. For a disaster to be entered into the database, at least one of the following criteria need to be fulfilled: Ten or more people reported killed, hundred or more people reported affected, declaration of a state of emergency and call for international assistance.

In this chapter, the types, distribution and trends in disaster impact and losses for the five major hazard categories; namely, drought, floods, epidemics, storms and geophysical hazards are discussed using available EM-DAT decadal statistics. Aspects of the other hazards that affect Africa, such as wildfires, dust storms and insect infestation, can be found in a previous report.² A physical hazard, by definition, is any event, phenomenon or human activity that may cause loss of life, social or economic disruption, or environmental degradation. A disaster is the impact of a natural or human-induced hazard that causes widespread human, material or economic losses beyond the coping capacity of a given society.³ Exposure encompasses the spatial and temporal distribution of a population and assets that are affected by a hazard. In other words, exposure characterises the assets at risk.³ In Africa, natural

and human-induced hazards continue to cause millions of victims and thousands of fatalities. A regional inventory of disaster losses, between 1960 and 2009 show that Africa is impacted severely by natural hazards, with hydro-meteorological hazards (mainly drought and floods) having the greatest impact. The continent is almost totally dominated by drought (Figure 1.1, a and b). For example, in the 1960-2009 period, drought accounted for 80.7 per cent of disaster victims and 79 per cent of disaster losses, while floods accounted for 12.1 per cent of victims and 2 per cent of losses. Storms contributed 3.9 per cent of disaster victims and 0.4 per cent of losses; geophysical hazards accounted for 0.35 per cent of victims and 2 per cent of fatalities. Epidemics accounted for 2.9 per cent of victims and 17 per cent of deaths. The regional-level data extracted from the database also shows that, for the major hazard categories under consideration, a total of 1 762 disasters have affected nearly 391 million people and killed 861 thousand people. By comparison, the EM-DAT database contains far fewer entries on disaster damage, especially for sub-Saharan Africa (SSA).

Single Hazard Impact

Droughts

A large part of SSA is susceptible to drought and on no other continent does drought appear to be as severe a risk as in Africa. As a result of the extensive arid and semi-arid areas and the extreme rainfall variability, drought contributes to loss of life, poor crop yields, famine, the mass migration of people from rural areas to towns, a decrease in water availability and spread of diseases, such as malaria. The impact of drought on society is slow and gradual. EM-DAT statistics show that droughts in Africa caused an estimated 680 000 deaths and claimed more than 316 million victims in the period 1960-2009.

The countries most affected by drought are Ethiopia, Somalia, Kenya and Mozambique in East Africa; Burkina Faso, Niger, Nigeria, Mauritania, Gambia, Ghana, Mali and Senegal in West Africa; and Botswana, South Africa, Lesotho, Swaziland and Namibia in southern Africa. The most serious consequence of drought is famine; however, drought and famine are not sudden events, but rather a consequence of unsound economic, agricultural and environmental strategies.⁴ Drought is further exacerbated by human action, such as deforestation, overgrazing and urbanisation.

Climate change is forecast to increase the intensity, frequency and duration of droughts in Africa. Nearly all climate change projections signal an increased chance of severe drought in southern Africa, particularly in the central and western areas.^{5,6} Future projections show a net overall global drying trend and the proportion of land surface affected by extreme drought is predicted to increase from one per cent (at present) to 30 per cent (by the end of the twenty-first Century).⁷ The drying trend is related to the anthropogenic emission of greenhouse gases and sulphate aerosols

into the atmosphere.⁷ Furthermore, it is projected that northern and southern Africa will become much hotter (by as much as 4-6°C) and drier in the summer, with a much greater risk of drought.⁸ In this respect, countries or regions with a Famine Early Warning System (FEWS) can and do benefit from El Niño/Southern Oscillation (ENSO) forecasts, which are essential for mitigating the impact of drought; they can also be useful in agricultural planning. ENSO refers to periods of unusually warm or cool sea surface temperature in the tropical eastern Pacific Ocean. For example, some drought years in Africa have been linked to the El Niño phenomena. Historically, these happened in 1882-1883, 1997-1998, 2002-2003, and in the current 2015-2016 period drought in Ethiopia is threatening the livelihood of more than 7,5 million people. Due to climate change, El Niño is forecast to happen more frequently. Thus, successful ENSO predictions, coupled with implementation strategies on the part of policy makers, can help reduce the human and economic toll of disasters on vulnerable populations. Africa's vulnerability is further exacerbated by uncontrolled population growth and economies dependent on rain fed agriculture. Thus, there is a clear need for drought risk management, as the situation is likely to worsen in the future with climate change.

Floods

Next to drought, floods and flash floods are Africa's most injurious disasters and they impact many countries. Floods are mainly concentrated along major river basins and in urban centres. A study of EM-DAT statistics shows that floods in Africa caused an estimated 17 000 deaths and produced more than 47 million victims in the period 1960-2009. The countries most often affected are Ethiopia, Somalia, Kenya and Mozambique in East Africa; Burkina Faso, Niger, Nigeria, Mauritania and Senegal in West Africa; and Botswana, South Africa, Lesotho, Swaziland, Namibia, and Angola in southern Africa. Harmful direct and indirect impacts of floods include: immediate deaths from drowning; widespread damage to crops, infrastructure and property; increased mortality from infectious diseases such as malaria, dengue fever, cholera and Chikungunya. While the primary cause of flooding is abnormally high rainfall, many human-induced factors contribute to flooding. These include: land degradation, deforestation of catchment areas, increased population density along river banks, poor land use planning and zoning, inadequate drainage (particularly in cities) and inadequate management of discharge from river reservoirs. Among some of the notable floods with a region-wide scope include: the 1997-1998, 2005, 2007, 2009, and the 2010-2011 floods. For example, the 2007 floods, that extended from Mauritania in the west to Kenya in the east were among the worst in decades and an estimated 1.5 million people were affected. Among the countries with highest mortality include: Angola, Algeria, Burkina Faso, Ghana, Mozambique, Nigeria, Sudan, Uganda, and Zaire. The recent, 2015 floods in eastern Africa, which killed hundreds of people and left thousands homeless have been linked to the El Niño phenomenon.

At present, emergency plans and flood forecasting systems are not well-developed to help mitigate from catastrophic flood losses. Expanded monitoring of floods, improved mitigation measures, and effective communication with vulnerable populations has the potential to reduce loss of life in future flood events. Thus, training and research should place emphasis on the prevention of floods. In addition, lack of hydrological data in many countries poses a challenge.

Storms

In Africa, storms mainly impact coastal countries and island states, such as Mozambique and Madagascar. Cyclones and hurricanes are weather systems characterised by severe winds and rainfall. These weather systems are known as 'tropical cyclones' in the Indian Ocean and 'hurricanes' in the Atlantic Ocean. They are generated between latitudes 5° and 20° when sea temperatures are sufficiently warm. Cyclones or hurricanes are capable of annihilating coastal areas through sustained winds with speeds of 250 km/h or higher; heavy rainfall; and most devastating of all are storm surges that cause the ocean level to rise by as much as 10 m. As a cyclone approaches land, a dome of ocean water of 80-160 km in diameter sweeps over the shoreline, causing coastal flooding and damage to coral reefs, mangroves and fisheries. The impact of these storms on coastal communities is exacerbated in cases where natural barriers, such as mangrove swamps, have been destroyed.

Storms caused an estimated 3 443 deaths and accounted for more than 15 million victims in the period 1960-2009. The southeast coast of Africa and the Indian Ocean islands (such as Madagascar, Seychelles, Reunion and Maldives), and the southeast coast of Africa are subject to the periodic impact of tropical cyclones. Typically, 12 cyclones occur annually in the southwestern Indian Ocean. A severe cyclone occurs about once a decade. Tropical cyclones can cause huge economic loss, especially in island states, by damaging dwellings, infrastructure (e.g. power, telecommunications and roads) and fisheries. Heavy rainfall can cause floods that damage infrastructure and crops, trigger landslides and spread disease.

Geophysical hazards

When compared to hydro-meteorological hazards, geophysical hazards (such as earthquakes and volcanoes) are spatially restricted, occur less frequently and impact fewer countries, located along the East African Rift System and the Cameroon Volcanic Line. As such, they have a much smaller impact on Africa. Geophysical hazards account for less than 0.5 per cent of all hazards that occur on the continent (Figure 1.1). Geophysical hazards caused an estimated 17 212 deaths and claimed 1 365 628 victims in the period 1960-2009. African countries such as Algeria, Morocco, Egypt, Cameroon, Uganda and the Democratic Republic of Congo (DRC) are most affected. However, the seismically active Atlas Mountain region of North Africa shows seismicity that is not restricted to narrow bands. This region poses a high

hazard risk because of the high density of its population and, historically, the region has seen high loss of human life and of property.

Active volcanoes also pose a serious threat to life and property in parts of Africa. The worst recorded disaster occurred at Lake Nyos (Cameroon, 1986), where a carbon dioxide emission killed 1 876 people and numerous cattle perished.⁹ A similar event took place at Lake Monoun, in 1984, killing 37 people. The continent has about 140 volcanoes that have erupted during the last 10 000 years, 25 of which are still active (that is, they have erupted during recent historical time, c. 500 years). The most disastrous volcanic eruption in Africa on record occurred at Mount Nyiragongo (DRC, January 2002). It killed 147 people and destroyed Goma, a town with over half-a-million inhabitants. The eruption of Mount Karthala in Comoros in April 2006 caused more than 10 000 villagers to flee their homes. Mount Karthala erupts in a cycle of approximately 11 years and previous eruptions have caused much damage to crops and pastures.

Epidemics

In the EM-DAT database Epidemics is defined as an unusual increase in the number of cases of an infectious disease; or the appearance of an infection previously absent from a region. It is classified as one of the main types of disasters in the biological disaster subgroup, together with insect infestation and animal accident, and is further subdivided into sub-types as: viral, bacterial, parasitic, fungal and prion diseases. A study of EM-DAT statistics shows that epidemics have caused an estimated 145 326 deaths and that the number of affected victims is 11 315 202 (Figure 1.1). However, the statistics on epidemics is not comprehensive as the number of recorded victims and deaths in the database is based on the adopted definition of epidemics mentioned above, and there is a lack of standardization of the terminology. Thus, there is a need to consult other classifications in the published literature for a more exhaustive information on epidemics mortality and morbidity. Among other classifications of epidemics in the published literature include: HIV/AIDS, Malaria, Cholera, Dengue Fever, Meningitis, Yellow Fever. Many African countries, including Kenya, Zimbabwe, Chad, Niger, Nigeria, Sudan, DRC, Tanzania, Burundi, Mozambique and Guinea Bissau, are heavily affected by epidemics. In recent decades, epidemics such as HIV/AIDS,¹⁰ malaria, cholera and meningitis have become increasingly severe. The frequency of cholera epidemics closely follows that of flooding (Figure 1.2). This is perhaps not surprising as cholera outbreaks and an increased incidence of malaria occur in flood-prone areas. In response to a changing climate, epidemics such as malaria and dengue may spread and become more severe.

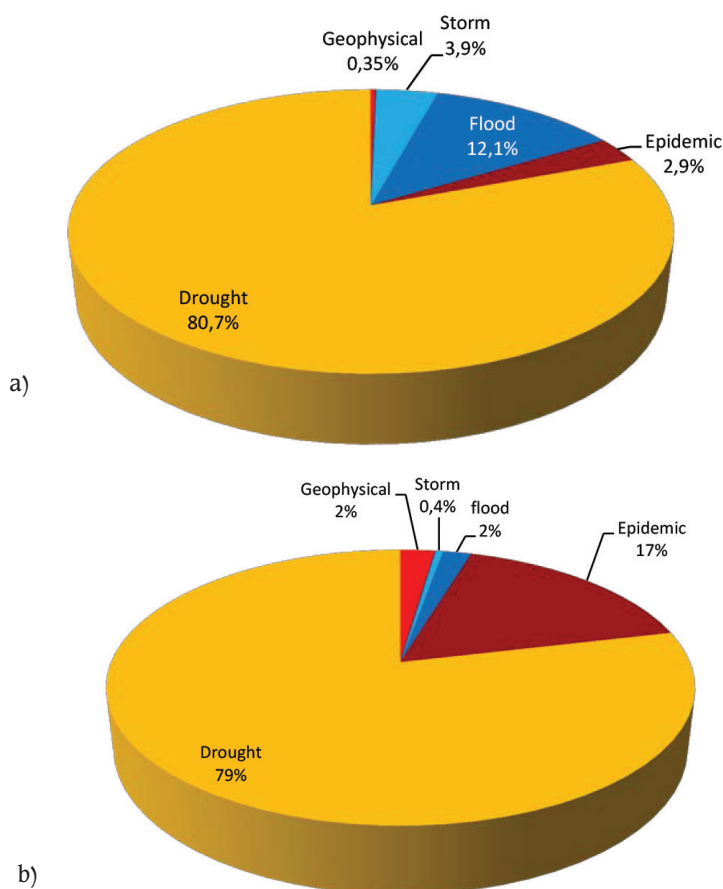


Figure 1.1: Disaster victims and fatalities by type (1960-2009). a) Affected; b) Killed.

Multiple Hazard Impacts

Analysis of the EM-DAT data shows that many African countries are affected by two or more main types of hazards (such as drought and floods) that can further aggravate the impact of single hazards, as discussed above. EM-DAT statistics for the period studied show that: 25 per cent of African countries are affected by five types of hazards; 38 per cent by four; 24 per cent by three; 9 per cent by two; and 4 per cent by one hazard type. This means that out of a total of 55 countries, 96 per cent are affected by two or more types of hazards. Moreover, hazards such as drought, floods and geophysical hazards have different patterns of occurrence in terms of their spatial distribution, temporal occurrence and event characteristics. For example, droughts affect many countries, cover large areas and represent relatively devastating events that produce millions of victims and thousands of fatalities. In contrast, storms and geophysical hazards are spatially restricted and have far fewer victims and fatalities (Figures 1.1 and 1.2).

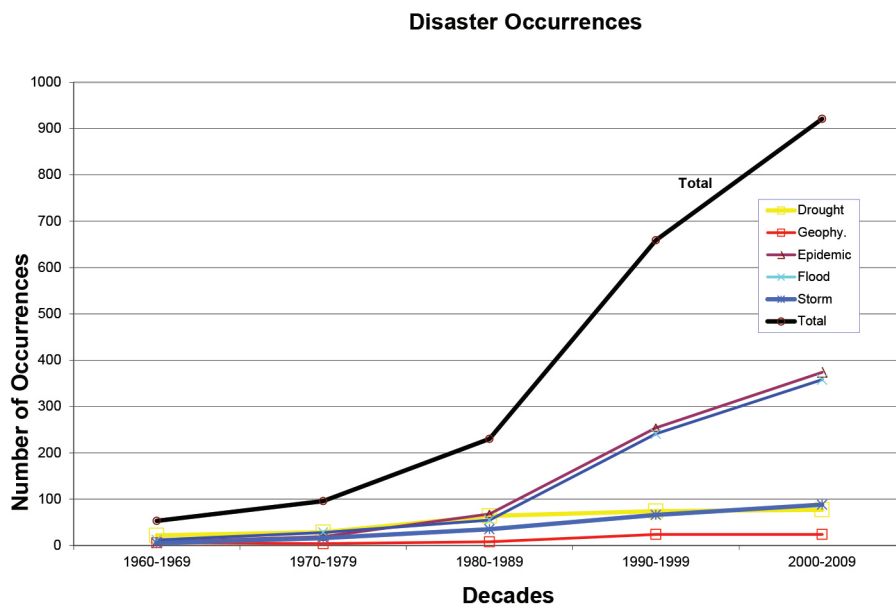


Figure 1.2: Frequency of hazards by type (1960-2009).

Table 1 Number of impacted countries by hazard type.

Types of Hazards	Impacted Countries
1	None
2	Libya, Sao Tome et Principe, Tunisia
3	Mauritius, Namibia, Reunion, Sierra Leone, Zambia, Angola, Burkina Faso, Cote d Ivoire, Eritrea
4	Ethiopia, Benin, Botswana, Cameroon, Central African Republic, Chad, Congo, Djibouti, Egypt, Gambia, Ghana, Guinea Bissaw, Leshoto, Liberia, Madagascar, Mauritania, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sudan
5	Algeria, Cape Verde Is., Comoros, Guinea, Kenya, Malawi, Morocco, Mozambique, Somalia, S. Africa, Tanzania, Uganda, Zaire

As African countries are threatened by several different types of hazards, vulnerability assessment and risk identification require a multi-hazard approach. However, as hazard events are so often interlinked, attribution of losses to any particular hazard

category can be difficult. For example, storms, floods and landslides can occur together, and volcanic eruptions are often associated with landslides and earthquakes. In Africa, it is indeed the cumulative impacts of disasters that lead to great human and property loss.

Disaster Trends

Analysis of disaster trends using EM-DAT statistics, aggregated at decadal time scales, shows that the impact and frequency of natural hazards and the human loss associated with these natural hazards continue to increase in Africa. For example, the frequency of recorded disasters has been rising rapidly, from about 53 per decade (in the 1960s) to 921 per decade in the 2000s. During the same period, the number of disaster victims increased six fold, from around 10 million in the 1960s to 179 million in the 2000s (Figures 1.2 and 1.3). In this respect, it is often questioned whether the increase in disasters is a result of: more scrupulous reporting and data availability; a physical increase in the magnitude or frequency of damaging events; or a human-driven increase in exposure or vulnerability.¹¹

Figures 1.3a and b provide a comparison of the trend in the number of victims and fatalities due to natural and human-induced hazards, at the regional level. The data, aggregated by disaster type, shows that while the number of people affected by disasters has been increasing over the past five decades, disaster fatalities do not show such a trend for the same time period. For example, drought alone caused nine million victims in the 1960s. This increased sixteen-fold to nearly 160 million victims in the 2000 decade (Figure 1.3a); however, the impact of drought on mortality was highest in the 1970 and 1980 decades and was surpassed by epidemics as the number one killer in the subsequent decades (Figure 1.3b). The high disaster losses in these decades most probably reflect the worst drought disasters of the time, which affected countries such as Ethiopia and countries in the Sahel region.

It is believed that many regions in Africa will suffer from the effects of droughts and floods with higher frequency and intensity due to climate change. However, questions on how climate change will directly impact risk patterns remain largely unanswered because current climate models are unable to predict specific alterations in weather patterns, storm severity or habitat degradation. Thus, more research is required for designing adaptation measures to withstand and cope with climate change. It is especially the poor who will bear the burden of climate change. With accelerating climate change, the traditional coping mechanisms and resilient livelihoods developed by poor people may be inadequate in the future. Thus, building the resilience of the most vulnerable in society is important for helping them withstand future disasters such as famine and water scarcity. The high disaster losses recorded by many African countries reflect not only the physical impact of the disasters but

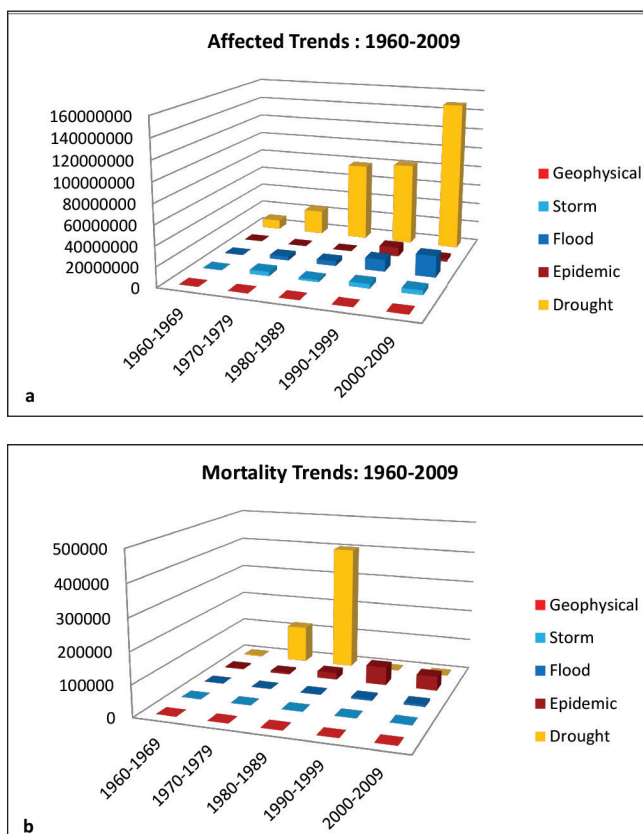


Figure 1.3: Trends in disaster victim numbers and mortality (1960-2009):
a) Victims; b) Mortality.

also the degree of human and societal vulnerability. However, the interactive link between the two has not been clearly distinguished and clarified as yet.

Vulnerability to Disasters

The United Nations Development Programme (UNDP)¹² defines vulnerability as a process that results from physical, social, economic and environmental factors that determine the capacity of people to anticipate, cope with, resist and recover from the impact of a given hazard. As discussed above, In the context of disaster analysis, vulnerability represents one component of risk, together with hazard impact and exposure. Thus, a disaster risk can differ greatly as a function of differences in exposure and vulnerability and in turn requires enhanced knowledge concerning the most vulnerable groups, the areas at risk and the driving forces that influence and generate vulnerability.¹³

While the continent houses many of the poorest and most vulnerable peoples in the world, African countries are doing little to prepare for disasters. In many situations, the financial resources and the political will required for effective disaster-impact reduction are lacking. Thus, for many people, especially in the Least Developed Countries (LDCs), a disaster is a compound event in which vulnerable people often suffer recurrent and mutually reinforcing shocks to their livelihoods because of the complex interaction of natural and human-induced hazards. These recurrent shocks have made it extremely difficult for people to cope and to maintain their livelihoods, as urgent survival needs remain unresolved across the continent and disaster risk reduction is not prioritised.¹⁴

In this respect, research is lacking on the socio-economic determinants of vulnerability, on resilience and coping strategies in public policies and practices, and on the improvement of early warning systems. There is also a need to develop the indigenous capability necessary for facilitating an exchange of information and experiences between countries, for understanding better the causes and consequences of natural hazards, including an analysis of the inter-connections between different kinds of hazards and a multi-hazard risk assessment. Such an exchange of information is essential for undertaking the necessary adaptation and mitigation measures for disaster reduction. Other limiting factors are existing policies that focus on short-term responsive measures rather than on proactive planning for longer-term adaptation and mitigation. Thus, it is clear that vulnerability analysis and disaster reduction need to be considered and addressed as an integral part of sustainable development.

Discussion

Analysis of disaster impacts and study of loss trends are very useful for prioritising disaster risk reduction measures and for assessing progress towards resilience. Seen in this light, a steadily increasing disaster loss trend observed in many countries strongly suggests that African societies are not resilient enough to withstand the perils of hazardous events. The question is: what controls the number of disaster victims and mortality? Is it mainly the hazard impact, or poor governance, or lack of adaptation and mitigation measures, or combinations of all of these factors? Currently the information available in the EM DAT database is not sufficient to answer these questions; however, it seems that it is a combination of the above-mentioned factors and population size that determines the number of fatalities and victims. For example, drought is pervasive and occurs over wide areas, in this way affecting many people and countries. In consequence, the high number of fatalities and victims due to drought, as compared to the other hazards, e.g., flooding, which is mainly concentrated along major river basins and in urban centres. In this respect, it goes without saying that accurate disaster loss data at all scales is necessary for undertaking

adaptation and mitigation measures and for identifying highly impacted countries and areas.

Disaster loss data is also essential for assessment of impacts and of trends in disaster frequency that are essential, for example, for studying the effect of human-induced climate change on development and settlement patterns and for post-crisis needs assessments and recovery planning. In particular, the EM-DAT database contains very little information on disaster damage or material loss in Africa, especially in SSA. Moreover, the database does not contain disaster information at local or sub-country level; thus, it is not possible to assess the spatial extent of disasters. In general, the pre 1970 statistics in the EM-DAT database show consistently fewer entries than in the post 1990 period. Thus, the country-level information in the database does not permit synthesis of the interlinkages between the full range of hazards and evolving human vulnerabilities at finer scales than the national level.

So, at present, African disaster losses are not recorded with sufficient detail to ensure understanding of the full context of the disaster. Moreover, little or no damage assessment is made to determine the direct and indirect losses per disaster event, nor are these events followed by detailed evaluations. This limits the possibility of identifying those most in need and at risk, especially in poorer communities and social groups and in remote geographical areas. In addition, lack of social statistics in relation to disaster events precludes a detailed record of loss. Overall, many African countries have not yet established mechanisms for loss accounting even if compilation of information on disaster risk and impact at all scales is one of the priorities of the Hyogo Framework for Action, 2005-2015.¹⁵ So it is not possible to assess in detail the causes of damage, including loss of property and crops. As property damage caused by African disasters is poorly documented in the EM-DAT database, little attempt is made in this paper to assess the economic impact of African disasters even though disasters are known to cause damage to assets such as buildings, crops, infrastructure and livestock, with a high economic impact in the context of a country's total GDP.¹⁶

Conclusion

In conclusion, the high disaster losses recorded in many African countries not only reflect the physical impact of the disasters but also the degree of human and societal vulnerability. However, at present, the link between the two is not clearly distinguished and clarified. This prompts the need for acquiring comprehensive and timely loss data necessary for sound policy and decision making for disaster risk reduction. Notwithstanding this the broad-scale analysis presented here is intended to identify major areas of concern at the regional level and not on the details of disaster impact and loss at country or local level. Thus, further studies at finer spatial scales are needed for assessing and resolving hazard risks and local vulnerabilities.

In this respect, a systematic analysis of disaster loss data is an essential first step in formulating public policies that are intended to monitor, assess and reduce Africa's vulnerability to natural and human-induced environmental hazards. What is most lacking at this stage is detailed information on human and material losses and on socio-economic vulnerabilities at both national and sub-national resolution to support risk management applications. Indeed, the success of disaster risk reduction measures requires a fundamental shift in focus from disaster response, as is the norm in Africa, towards cost-effective evidence-based disaster mitigation and adaptation measures. It is also important to view adaptation to and mitigation of hazards as an integral part of sustainable development.¹⁷

This overview is based on historical loss data and, as this can change with time, a continuing need will exist for updating the information on the complex and inter-linked factors such as urbanisation, environmental degradation and climate change. The need for updated information, in turn, prompts the need for translating research findings on natural and human-induced hazards and disasters into policies and programmes that are effective in minimising the rising human toll from and the economic costs of disasters.

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Part I

Geophysical Hazards

CHAPTER 2

Earthquakes in Africa

Raymond Durrheim

Introduction

Earthquakes were responsible for some of the most devastating disasters that occurred in the early years of the twenty-first Century.¹ On 26 December 2004, a M_w 9.1 earthquake occurred off the coast of Sumatra, which triggered a tsunami that swept across the Indian Ocean. Some 228 000 people perished and about 1.7 million people were displaced in 14 countries in South Asia and East Africa. Somalia was the African country that was hardest hit, while the tsunami caused damage along the coastlines of Tanzania, Madagascar and other Indian Ocean islands.² On 12 January 2010, a M_w 7 earthquake struck Haiti. Official estimates indicated that: about 316 000 people were killed and 300 000 injured; 1.3 million people were displaced; and almost 97 000 houses were destroyed in the Port-au-Prince area and southern Haiti. Other estimates suggest substantially lower numbers of casualties – perhaps fewer than 100 000. The M_w 9.0 Great Eastern Japanese earthquake and tsunami struck on 11 March 2011. According to Munich Re, one of the world's biggest reinsurance companies, it was the costliest disaster of all time. Losses amounted to US\$210 billion, excluding the cost of the incident at the Fukushima nuclear power station.³

Fortunately, large earthquakes are relatively rare in Africa. However, Africans cannot afford to be complacent. It has been said, *'Earthquakes don't kill people; buildings do'*. A moderately sized earthquake, with a shallow focus, that occurs close to a town can be devastating, especially if: the buildings are not designed to be earthquake-resistant; the terrain is steep and prone to landslides; the weathered layer is very thick; or water-saturated sediments that are prone to liquefaction are present. One such earthquake struck Agadir, a town on the Atlantic coast of Morocco, on 29 February 1960. The M_w 5.7 event killed some 13 000 people – over one-third of the population – while at least another third was injured. It was the deadliest earthquake to strike Africa since 1900 and the most destructive 'moderate' quake (magnitude of less than six) anywhere in the world during the twentieth Century. The event was shallow and right under the city. Sadly, the destruction of a previous town at this location (Santa Cruz de Aguer) by an earthquake in 1731 had been forgotten and few buildings had been built to seismic codes.

In 2006, 46 years after the deadly earthquake, a survey was conducted into the perceptions of risk held by residents of Agadir, as well as the implementation of mitigation measures.⁴ Agadir had been rebuilt and had become a prime tourist destination; and the population had increased to more than 680 000. The researchers interviewed survivors of the 1960 earthquake and conducted a survey of the perceptions, judgements and conclusions that residents drew from the disaster. Most people attributed the likelihood of surviving an earthquake to religious devotion, rather than to the quality of building construction. Most did not understand the importance of reinforcement and thought that a building would be safe from earthquakes as long as concrete was used in its construction. Consequently, many buildings constructed in Agadir since 1960 are only partially reinforced, or completely without reinforcement, leaving them vulnerable to collapse.

The case of Agadir illustrates the urgent need for African scientists and engineers to transfer their knowledge to government officials and the general public. In this chapter, I describe the risk that earthquakes pose to African communities and the measures that can be taken to reduce these risks and so prevent disasters from occurring.

Cause of Earthquakes

Early ideas

In the pre-scientific era, the forces of nature were often ascribed to the actions of mythical creatures or supernatural beings, and African cultures were no exception. For example, the Egyptians of the 8th dynasty attributed thunderstorms and earthquakes to the actions of Apep, the deity of darkness and chaos.⁵ Apep was usually represented as a giant serpent. Interestingly, a snake also features in the creation myths of the Fon people of West Africa. Many accounts tell of how Mawu, the mother of all the gods and humanity, created everything while Aido Hwedo, the rainbow serpent, carried her from place to place. The winding motions of the snake created the Earth's landforms. Afterwards, Mawu asked Aido Hwedo to encircle the Earth and support its weight. An earthquake or tidal wave occurs whenever Aido Hwedo shifts or re-adjusts his position.^{6,7} The Tonga people that live in the Zambezi Valley hold Nyaminyami, a river god believed to be half-snake and half-fish (Figure 2.1), to be responsible for the tremors induced by the impoundment of the Kariba Dam:⁸

'At the time of the closing of the dam, Nyaminyami's wife had gone downstream of the Kariva, now Kariba Gorge, to answer the prayers of her people and bless them. When it was time for her to return to her husband, she could not cross because of the dam wall and this angered Nyaminyami. From then, until today, Nyaminyami is still upset and the

occasional tremors felt in the lake are caused by the spirit. The tremors occur when Nyaminyami, it is believed, tries to break the wall and cross to the other side, where his wife is, and at the same time show his people that he still exists and is powerful’.



Figure 2.1: A carving of Nyaminyami, the river creature traditionally believed to cause earthquakes, which overlooks Kariba Dam.⁹

Plate Tectonics

In 1858, an Irish civil engineer named Robert Mallet, sometimes known as ‘the father of seismology’, published a global map of earthquake epicentres.¹⁰ It was obvious that most earthquakes occurred in distinct zones, particularly in the Pacific Ocean and near high mountain ranges, such as the Alps and Himalayas.

Seismometers were invented in the 1880s and, by the early decades of the twentieth Century, sufficient earthquakes had been recorded at distances great enough to allow seismologists to analyse the travel time of seismic waves that had traversed the Earth’s deep interior. It was deduced that: the Earth has a metallic core with a radius of about 3 600 km; this is surrounded by a mantle, about 2 800 km thick, composed of dense silicate minerals, and a 5-80 km-thick crust, composed of lighter silicate minerals.

At about the same time (ca. 1912), the German meteorologist, Alfred Wegener, noticed a good fit between the African and American continents and hypothesised that the continents had drifted apart. Inspired by Wegener’s hypothesis, the South African geologist, Alexander du Toit, conducted an expedition to South America to investigate similarities between the geologies of the two continents. In 1927, he

published (with F.R.C. Reed) *A Geological Comparison of South America with South Africa*, in which the authors reviewed stratigraphic and radioisotope evidence that supported Wegener's ideas. Du Toit amplified these findings in his best-known work, *Our Wandering Continents*, published in 1937. The force driving continental drift remained a mystery until the 1960s, when geologists and geophysicists integrated many diverse observations. These included paleomagnetic studies, which provided evidence of the movement of continents; measurements of the magnetisation and age of the oceanic crust, which provided evidence of sea floor spreading; the location, depth and rupture mechanisms of earthquakes; and the flow of heat from the Earth's interior. A theory that explains most of the Earth's main geological features was developed.

In brief, the Theory of Plate Tectonics postulates that the Earth has an outermost shell that is more or less rigid (known as the 'lithosphere') and consists of about a dozen 'plates' that move relative to each other. The lithosphere consists of the crust and the uppermost parts of the mantle. Plate movement is driven by slow convection of the rock in the deeper mantle, powered by heat produced by the decay of radioactive elements within the Earth's core. The plastic convecting zone beneath the lithosphere is known as the 'asthenosphere'. The relative velocities of the plates are small (at most 15 cm/year, typically about 5 cm/year, and sometimes less than 1 cm/year); but, over millennia, these small movements open wide oceans and build high mountain ranges. With the advent of satellite and global positioning system (GPS) technology, it is now possible to measure the motion directly: Africa is moving northwards relative to Eurasia at a rate of approximately 1 cm/year; while the distance between Africa and South America is increasing by about 10 cm/year. To relate this to human experience, our fingernails grow at a rate of about 5 cm/year.

The motion along plate boundaries is not smooth, but jerky, or 'stick-slip'. Most of the time, the boundaries are locked together, the plates deform and elastic energy is stored. From time to time, the elastic forces in the plate exceed the frictional forces that clamp a pre-existing fault and slip occurs. Most of the stored elastic energy is converted into frictional heat, but some of the energy spreads out as seismic waves, causing the Earth to shake.

New crust is created where mantle convection currents well up; for example, along the long volcanic ridges that lie in the middle of the Atlantic and Indian oceans, as well as in continental rifts such as the East African Rift System (which may eventually split the African continent). Mid-ocean and continental rifts are known as 'divergent plate boundaries'. The East African Rift is widening at a rate of 1-2 cm/year. Earthquakes with a magnitude of greater than 6 occur regularly. Four earthquakes with a magnitude that is equal to or greater than 7 have been recorded since 1900, the largest being a M_s 7.3 event that occurred in Tanzania in 1910.¹¹ (The different magnitude scales, such as M_w , M_s and M_L , are explained later in the chapter.)



Figure 2.2: The East African Rift, an example of a divergent continental plate boundary.¹²

Crust is destroyed when relatively dense oceanic crust dives beneath another plate, forming a convergent plate boundary. For example, the Pacific Plate is plunging beneath the western edge of the South American Plate. This phenomenon is termed ‘subduction’. Continental crust is relatively buoyant and resists subduction into the mantle, so, when the continental parts of plates collide, the continental crust crumples and fold mountains are formed. For example, the Atlas Mountains were formed by the collision of the African and Eurasian plates. The largest instrumentally recorded earthquake to occur in a continental collision zone in Africa was a $M_w 7.1$ event that occurred on 10 October 1980 in Algeria, with its epicentre near the town of El Asnam (formerly Orleansville). At the third type of boundary, crust is preserved as the plates slide past one another. This is known as a ‘transform plate boundary’. The most famous example is probably the San Andreas Fault, which stretches between Los Angeles and San Francisco along the western margin of North America. Earthquakes occurring offshore of Ghana are believed to be related to shear zones related to oceanic transform faults, such as the $M_L 6.5$ event that struck Accra in 1939.¹³

Globally, the largest earthquakes occur in subduction, collision and transform fault zones, while those in rift zones generally do not exceed $M_w 7.5$. The largest earthquakes, such as the one that triggered the Indian Ocean tsunami in December 2004, may exceed $M_w 9.0$ and rupture more than 1 000 km of crust, with a maximum slip of several tens of metres.

The African continent is largely a tectonically stable intra-plate region. Except for its northern boundary, Africa has been surrounded by spreading ridges since the break-up of Gondwana about 120 million years ago. A narrow belt of earthquakes

along the Mid-Atlantic and Mid-Indian oceanic ridges defines the boundaries of the African Plate. The only parts of Africa that do not display the characteristics of an intra-plate region are the East African Rift System (and its continuations into Botswana and Mozambique), the Cameroon Volcanic Line and the Africa-Eurasia collision zone. The rest of Africa is characterised by a relatively low level of seismic activity, with earthquakes randomly distributed in space and time. However, it is important to note that global observations show that intraplate earthquakes, while rare, can occur, even without significant precursory seismic activity, and may have large magnitude and cause considerable damage.

Measuring the size of earthquakes

‘Intensity’ and ‘magnitude’ are the two main measures that are used to describe the size and effects of earthquakes.

Intensity

‘Intensity’ refers to the degree of shaking caused by a particular event; it is based on phenomena such as human perceptions of shaking and the degree of damage caused to structures. Various intensity scales have been devised and calibrated against measurements of ground motion. In the widely used Abridged Modified Mercalli Scale, an intensity of: III indicates ground motion that is perceptible to people, especially on the upper floors of buildings; VI is felt by all, many people are frightened and run out of doors, and a few buildings may be slightly damaged; VIII causes slight damage to earthquake-resistant structures, considerable damage to solid buildings, and great damage to poorly-built buildings; while XII indicates total destruction, with objects thrown into the air.

An earthquake’s ‘epicentre’ is the point on the surface directly above the point inside the Earth where the rupture initiates, which is called the ‘focus’ or ‘hypocentre’. Intensity generally decreases with distance from the epicentre, although isoseismal lines are only roughly concentric, as the amplitude of the ground motion depends on numerous factors, such as the thickness and properties of the soil, the topography, the length and orientation of the fault, and the direction of propagation of the rupture. The strength of buildings must also be taken into account when assessing intensity, as the degree of damage may vary greatly, depending on construction techniques.

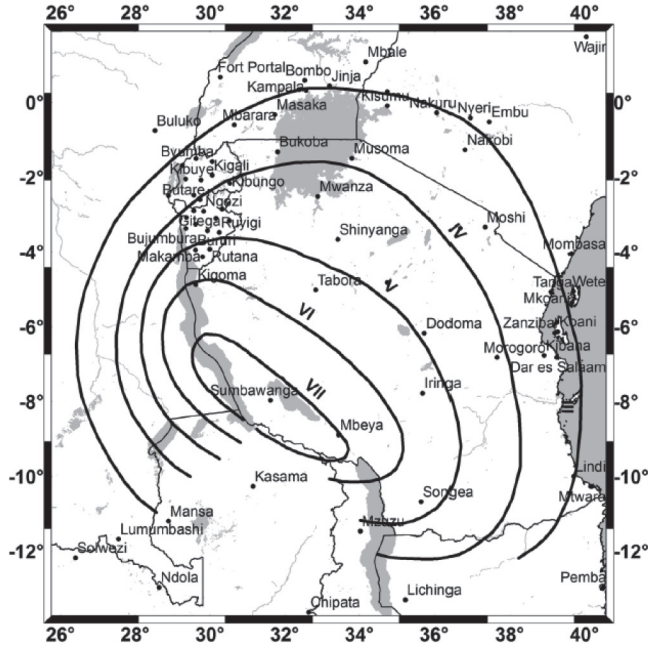


Figure 2.3: Intensity map for the Rukwa earthquake that struck Tanzania on 13 December 1910.¹⁴

Magnitude

The measurement and comparison of earthquake size is not a simple matter. Many different magnitude scales have been devised and used in various regions and historical periods; and many different seismometers have been used since their invention in the 1880s, each with its unique response characteristic. Furthermore: radiation of energy by an earthquake is not symmetric; and the estimation of ground motion produced by a particular earthquake depends on the spatial distribution of seismometers. These factors must be taken into account when estimating magnitudes and compiling and harmonising earthquake catalogues.

Commonly used magnitude scales include the Richter, local (M_L), body wave (m_b) and surface wave (M_s) scales. Seismologists generally use the ‘moment magnitude scale’ (M_w) to describe the size of the earthquake source in terms of the area of rupture, displacement along the fault and the strength of the fault. The seismic moment is derived from the entire seismogram, taking the amplitude and frequency of the ground motion into account. It should be noted that the magnitude scale is logarithmic; thus, a difference in magnitude of one unit corresponds to a 10-fold difference in the amplitude of shaking and a 32-fold difference in the amount of energy released.

The largest earthquake ever recorded by instruments was a M_w 9.5 event that occurred in the Chilean subduction zone in 1960. Generally, only earthquakes with

$M_w > 6$ cause significant damage, with the devastating $M_w 5.7$ Agadir earthquake of 1960 being a notable exception.

Recurrence time

There is a robust statistical relationship between the magnitude and average recurrence time of earthquakes, known as the ‘Gutenberg-Richter relationship’:

$$N = a - b \log M$$

Where:

N is the number of earthquakes greater than magnitude M ; a is the activity rate, or number of events with $M > 0$ in a year; and b is the slope of the frequency-magnitude relationship, which gives an indication of the relative number of large and small events.

Worldwide, b generally has a value of close to 1.0. This means that for every earthquake greater than a given magnitude, there are likely to be 10 earthquakes greater than the magnitude one unit smaller (e.g. for every earthquake greater than $M_w 7$ that occurs in a particular region, 10 earthquakes greater than $M_w 6$ are likely to occur). Worldwide, about 20 events with $M_w > 7$ occur every year, as well as about 200 events with $M_w > 6$, and 2 000 with $M_w > 5$. The relative scarcity of large events makes it very difficult to determine the size of the largest event that could possibly occur in a given region, and hence to assess seismic hazard, especially if the earthquake catalogue is only a few decades in length or is incomplete, and seismicity levels are low. The distribution of seismicity and the frequency-magnitude distribution for Europe, Africa and the Middle East are shown in Figure 2.4.

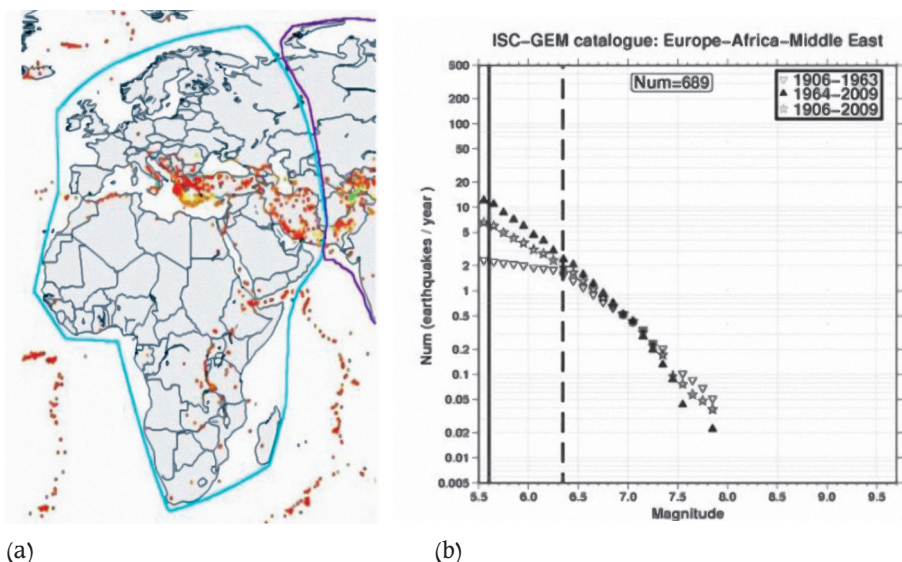


Figure 2.4: (a) Map showing the locations of events in the ISC-GEM earthquake catalogue; (b) Cumulative frequency-magnitude distributions for the Europe – Africa – Middle East region for 1906-1963, 1964-2009 and 1906-2009.

Earthquake Catalogues

In order to assess the risk posed by earthquakes, it is important to have a record of past earthquake activity. A catalogue is simply a list of the epicentre, time and magnitude of past earthquakes. These parameters are best known if the earthquake was recorded by seismographs. However, the global instrumental catalogue is not much longer than a century and, in many parts of the world, the recurrence time of the largest plausible earthquake is much longer than this. Thus, historical records, while less accurate and complete, are vital supplements to instrumental catalogues. However, the historical record is often only a few centuries long and inevitably incomplete. Thus, paleoseismologists seek to extend the catalogue back in time by discovering and deciphering clues left by prehistoric earthquakes.

Instrumental catalogues

By the beginning of the twentieth Century, sufficient seismographs had been deployed around the world to ensure that all events with $M > 7.5$ were recorded. As the decades passed, the number and sensitivity of seismographs increased and the magnitude of completeness steadily decreased. The International Seismological Centre (ISC) curates the global earthquake catalogue. The global ISC-GEM catalogue for Africa is considered complete: above $M_s 7.5$ since 1900; above $M_s 6.25$ since 1918; and above $M_s 5.5$ since 1960.¹⁵ The Global Earthquake Model (GEM) Regional Programme for sub-Saharan Africa¹⁶ is seeking to enlarge this catalogue, by sourcing and harmonising catalogues produced by national seismograph networks.

Of all the inhabited continents, Africa has the sparsest distribution of seismographs. In many countries, the maintenance of seismic stations has not been a priority and there are significant gaps in the seismic catalogue. Furthermore, recurrence times are large in most parts of Africa. Together, these factors make it difficult to achieve a reliable assessment of seismic hazard in Africa. This situation can only be remedied by a concerted effort to maintain and expand national and regional seismograph networks.

Historical catalogues

Historical catalogues are compiled from records that describe the effects of earthquakes that occurred in the pre-instrumental period (prior to, say, 1900), such as accounts of damage to buildings, surface rupture and landslides. Empirical relationships that relate the maximum intensity to magnitude are used to estimate earthquake magnitudes. The historical record is longest in regions such as China, the Middle East and Italy, where it stretches back for more than two millennia. However, in many other parts of the world, the reliable historical record is less than five centuries. A few examples of historical African earthquakes and catalogues are given below.

Reference to eight destructive earthquakes that affected the Alexandria region of North Africa between 320 and 1 303 have been found in Greek, Latin, Byzantine and Arabic texts.¹⁷ The most destructive effects were produced by tsunamis generated by earthquakes located near Crete, where the African plate subducts under the Eurasian plate. A Special Session, entitled *The Discovery of the Sunken Cities of Alexandria*, was held at the Fall Meeting of the American Geophysical Union (AGU) in 2000. The discovery of two collapsed and sunken cities (Menouthis and Herakleion/Thonis) under 6-8 m of water in the Bay of Abuokir was reported in a series of papers. The collapse of the cities was attributed to earthquake shaking, based on archaeological evidence of sheared walls and rows of fallen columns, while the subsidence was attributed to earthquake-induced liquefaction and/or slumping.¹⁸ Other researchers believe that the subsidence might have been unrelated to earthquakes and induced by flooding of the Nile.¹⁹ The case of Alexandria raises the concern that the current picture of plate boundaries and models of plate motion may not be a very reliable guide for the occurrence of destructive earthquakes, either in the distant past or the near future.

The record of the historical seismicity of Algeria prior to 1900 is imperfect; but it is of critical importance for hazard assessment, as it reveals the main features of seismic activity in a region where the level of seismic activity is medium to low.²⁰ The earliest known event occurred in 419 and was mentioned by St Augustine, while destructive events also struck Algiers in 1 365, 1 673, 1 716 and 1 825. A catalogue of historical seismicity for the Maghreb region of North Africa lists more than 100 events between 846 and 1 900.²¹

The earliest documented earthquake in Ghana was in 1615, when the fortress of Sao Jorge at Elmina was destroyed. On 18 December 1636, an earthquake shook the Axim district (near the border of Ghana and the Ivory Coast), causing the workings of the gold mine at Aboasi to collapse, burying many miners.²²

The earliest event in the South African historical catalogue is dated at 1 620.²³ However, a recent re-examination of historical records reached the conclusion that the event, recorded by the captain of a ship anchored in Table Bay, was most likely a thunderclap and not an earthquake,²⁴ with the result that the oldest event in South African is now dated at 1690. The most damaging event to strike Cape Town in the pre-instrumental era occurred on 4 December 1809. Three strong quakes were felt and many buildings suffered numerous cracks. Wilhelm von Buchenröder²⁵ provided an eyewitness account of the events of 4 December 1809:

'In the evening, a little after ten o'clock, three shocks, each accompanied by a tremendous noise, were felt, within the space of a minute or two. When the first took place, I was sitting in a large company, all the members of which started simultaneously and hastened to the door, the majority exclaiming that a powder magazine must have blown up, while

one gentleman called out that it was an earthquake, adding he was acquainted with such, from having experienced some on his voyages to the West Indies. While we were standing in the street, the second shock took place, which was felt much stronger, was accompanied by a louder, and very tremendous noise that continued longer than the first, and resembled the report or sound that would be produced by a great many pieces of Ordnance fired off by a train at a little distance ... The second shock roused all the inhabitants, who came running into the streets in great consternation, many of them undressed from having been in bed'.

The next day, Von Buchenröder undertook an inspection of the town and noted that chimneys, parapets and figurines on gables were damaged; several days later he made quantitative observations of the surface rupture. This information has made it possible to deduce the intensity and magnitude as being VII-VIII (on the Modified Mercalli Scale) and M_L 6.1 respectively.

Paleoseismicity

The challenges in determining the epicentre, date and size of earthquakes that occurred prior to historical records (say in the last 100 000 years) have given rise to a discipline known as 'paleoseismology', which integrates the output of many other disciplines. For example: geomorphological features such as fault scarps and river knick points can be used to deduce the length and displacement of the rupture caused by a particular earthquake; while geochronological techniques can be used to determine the age of sediment deposited along fault scarps and hence the minimum age of the earthquake.

In 2009, paleoseismic studies of the southeastern continental margin of South Africa were carried out at proposed sites for nuclear power stations, as part of the required seismic hazard assessment.²⁶ This region has little seismic information and the record is too short to include the long recurrence intervals of large, surface-damaging earthquakes typical of intraplate regions. A scarp running parallel to the Kango Fault in the Cape Fold Belt was interpreted to be the surface expression of an 84 km-long extensional surface rupture (Figure 2.5). A trench 80 m long, 6 m deep and 2.5 m wide was dug across the fault, exposing 21 lithological units, six soil horizons and 19 fault strands. Vertical displacement indicated a fault throw of about 2 m. Optically stimulated luminescence (OSL) dating indicated that the fault was active between 12 200 and 8 800 years ago, and most probably around 10 600 years ago. The magnitude was estimated to have been M_w 7.4, based on published relations between surface rupture length, displacement and magnitude.

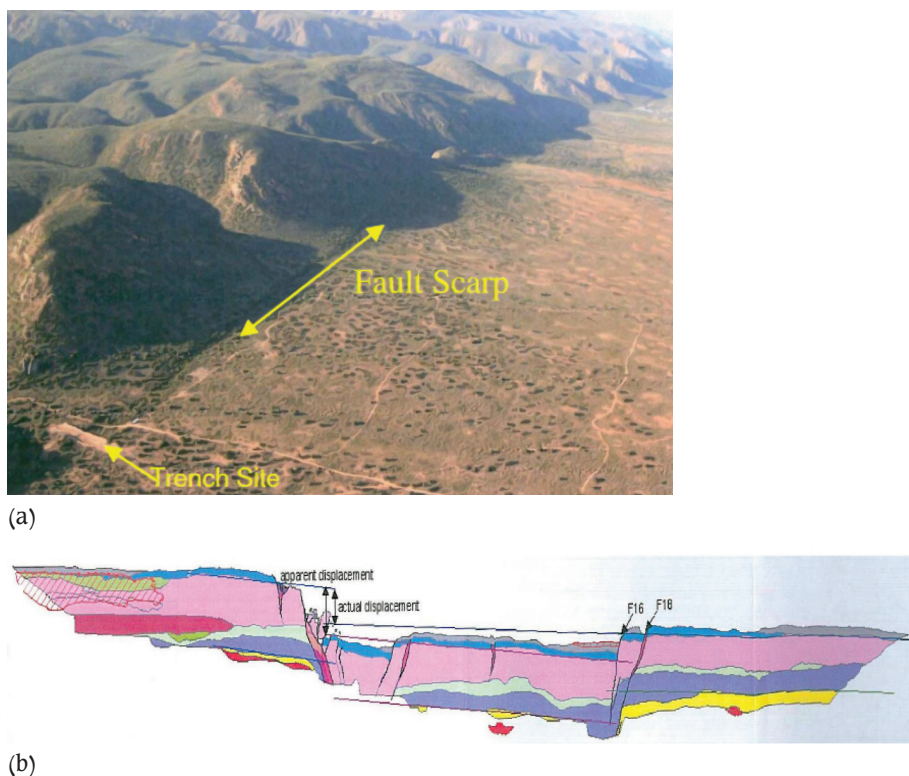


Figure 2.5: Paleoseismic investigation of the Kango Fault, Cape Fold Belt, South Africa.²⁷ (a) Part of the 84 km long and 2 m high fault scarp produced by a M_w 7.4 event about 10 600 years ago, and the trench site. (b) Geological map of the trench wall (80 m long x 6 m deep).

Earthquake hazard

A hazard is defined as any event, phenomenon or human activity that may cause a loss of life, property or economic activity; risk is the combination of the probability of an event and its negative consequences; a disaster is defined as an event that exceeds the ability of the affected community or society to cope, using its own resources.²⁸ Earthquakes, along with phenomena such as tsunamis, volcanoes, explosive crater lakes, landslides, mudflows, erosion and siltation, are generally termed 'geohazards'. Geohazards and hydro-meteorological hazards may compound each other. For example, both earthquakes and heavy rainfall may trigger landslides; thus, an earthquake that occurs during the wet season is even more likely to trigger a landslide. Furthermore, natural and human-induced phenomena may act together to create a hazard. For example, mining activity, the impoundment of large dams or the injection of fluids into geological formations may trigger earthquakes. The Great Eastern Japanese Earthquake of March 2011 is a classic example of a 'disaster cascade'. The earthquake triggered a tsunami, which disrupted the supply of power

to pumps that cooled the Fukushima Nuclear Power Station, leading to a meltdown of the reactor and, finally, radioactive contamination of the countryside.

Hazard assessment is the process of determining the likelihood that a given event will take place. A probabilistic seismic hazard assessment (PSHA) is generally expressed in terms of the ground motion that has a certain likelihood of exceedance (say 10 per cent) in a given period (say 50 years). Many PSHA schemes are available, but all require a catalogue of earthquakes (size, time, location), characterisation of seismically active faults and areas (usually in terms of the maximum credible magnitude and recurrence times), and a prediction of the variation in ground motion with distance from the epicentre. The longer the duration of the catalogue, the smaller the magnitude of completeness and the better the zonation, the more reliable is the PSHA.

PSHA may be carried out on many scales. During the 1990s, the Global Seismic Hazard Assessment Programme (GSHAP) compiled and published a seismic hazard map for the whole world.²⁹ The GSHAP map for Africa^{30,31} is shown in Figure 2.6. It is currently being updated under the auspices of the GEM initiative.³² Sometimes a 'worst-case scenario' will be investigated, considering the maximum credible event on a nearby fault. This is termed 'deterministic seismic hazard assessment'. Factors such as the rupture process, attenuation in the crust and amplification effects caused by soil and topography are taken into account.

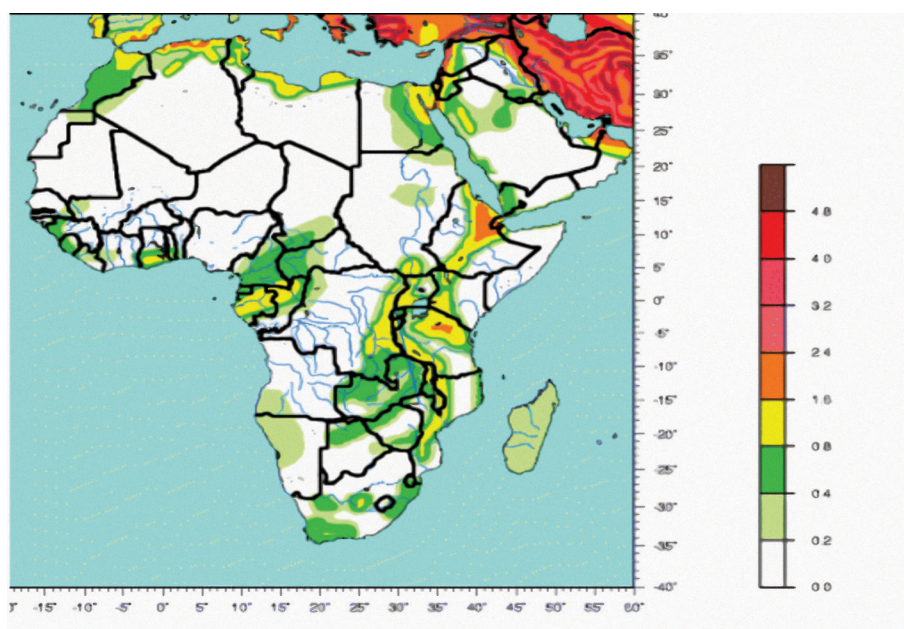


Figure 2.6: GSHAP seismic hazard assessment for Africa, showing the peak ground acceleration (m/s^2) with 10 per cent probability of exceedance in 50 years.³³

Case Studies of Tectonic Earthquakes

In this section, I briefly review tectonic earthquakes that have caused significant loss in Africa in the last 60 or so years. The primary source of information is the US Geological Survey website,³⁴ which hosts information on earthquakes that have occurred since 1900 and caused more than 1 000 deaths. North Africa, and particularly the Maghreb region, is affected by the collision of the African and Eurasian plates; East Africa is affected by the continental rift; while the rest of the continent is subject to intraplate seismicity.

North Africa

M_s6.7, Orleansville, Algeria, 9 September 1954: The M_s6.7 earthquake caused severe damage in the Orleansville area. About 1 250 people were killed and 3 000 injured. Faults and fissures occurred in a 16 km-long zone at the southern edge of the Dahra Massif. Under-sea cables in the Mediterranean broke several hours after the earthquake. There were many aftershocks, and a strong shock on 16 September caused additional damage. Orleansville was rebuilt and renamed El Asnam (now Chellif).

M_w5.7, Agadir, Morocco, 29 February 1960: About 15 000 people (about one-third of the town's population) were killed and at least another third injured by this short-duration earthquake, which lasted less than 15 seconds. In some districts, all buildings were destroyed or very severely damaged and more than 95 per cent of the people killed.

M_w7.1, El Asnam, Algeria, 10 October 1980: Shaking was felt throughout north-western Algeria and in southeastern Spain. Approximately 42 kilometres of surface rupture were observed. At least 5 000 people were killed, 9 000 were injured and extensive damage was caused in the El Asnam area.

M_w5.8, Cairo, Egypt, 12 October 1992: The earthquake had a magnitude of less than 6, but was unusually destructive for its size, causing 545 deaths, injuring 6 512 and making 50 000 people homeless.³⁵ Most of the severe damage was confined to older masonry structures, particularly those built of adobe. Liquefaction was reported from areas near the epicentre.

M_w6.8, Boumerdès-Zemmouri, Algeria, 21 May 2003:³⁶ At least 2 266 people were killed, 10 261 injured and about 180 000 made homeless, and more than 43 500 buildings were damaged or destroyed. The maximum intensity was rated as X on the Modified Mercalli Scale. Under-water telecommunication cables were cut and landslides, sand blows, liquefaction and ground cracks were observed. A maximum ground acceleration of 0.58g was recorded. Damage was estimated at between US\$600 million and US\$5 billion. About 40 to 80 cm of uplift of the sea floor was measured along the coast, and a tsunami, with a maximum estimated wave height of 2 m, caused damage to boats in the Balearic Islands.

M6.4, Al Hoceima, Morocco, 24 February 2004:³⁷ The earthquake caused about 630 deaths, while close to 1 000 people were injured. About 2 500 homes were destroyed and more than 15 000 people made homeless (Figure 2.7). The maximum intensity was IX, with a maximum recorded horizontal acceleration of 0.24g.



Figure 2.7: Damage caused by the M6.4 earthquake that struck Al Hoceima, Morocco on 24 February 2004.³⁸

East African Rift System

M_w7.0, Machaze district, Mozambique, 22 February 2006: The earthquake struck just after midnight, local time. The shaking was sufficiently strong to cause many residents of Maputo and Beira to flee into the streets and for it to be felt in South Africa (Durban, Johannesburg and Pretoria), Zambia and Zimbabwe. The epicentral region is sparsely populated; but at least 288 houses, 6 schools and 2 small bridges were destroyed, 4 people were killed and 36 were injured.³⁹ Three segments of the fault rupture, with a combined length of some 15 km, were surveyed.⁴⁰ An average vertical displacement of 1.0–1.5 m was observed, with offsets of 0.7 m in one segment left-lateral, as well as spectacular liquefaction features, such as sand blows with a diameter of 5–8 m, and a 318 m-long liquefaction fissure (Figure 2.8). However, it was not possible to decide if the earthquake was on an ‘old, slow fault’, similar to those found in intraplate regions, or a new structure related to the southward propagation of the East African Rift.⁴¹



Figure 2.8: Surface rupture of the M_w 7.0 earthquake that struck the Machaze district, Mozambique, on 22 February 2006.^{42,43}

M_w 5.9, Lac Kivu region, Democratic Republic of Congo (DRC)/Rwanda, 3 February 2008:⁴⁴ Seven people were killed, with over 400 injured, and 1 000 houses were destroyed in Bukavu, DRC (Figure 2.9); in Rwanda, 37 people were killed and over 600 injured, and 1 200 houses were destroyed.



Figure 2.9: Damage in Bukavu, DRC, caused by the M_w 5.9 earthquake that struck the Lake Kivu region on 3 February 2008.⁴⁵

Swarm of four earthquakes in the range M_w 5.4- M_w 6.0, Karongo Region, Malawi, 6-19 December 2009: Four people were killed and about 300 injured, while over 1 000 houses collapsed.

West Africa

M_L 6.4, Accra, Ghana, 22 June 1939:⁴⁶ Although Ghana is remote from present-day plate boundaries, it has experienced several destructive earthquakes in historical

times, notably a $M_L 6.4$ event that struck Accra on 22 June 1939, with the reported death toll ranging between 17 and 22. Efforts to mitigate earthquake risk in Ghana are discussed in Section 8.2 below.

$M_w 6.3$, Guinea, 22 December 1983:^{47,48} The earthquake, in an intraplate region of West Africa that was previously thought to be essentially aseismic, killed at least 275 people, injured more than 1 000 and left 18 000 people homeless. The main shock was associated with at least 9 km of surface rupture, with fault displacement: of up to 13 cm of right-lateral strike slip; and 7 cm of vertical movement. Extensive rockfalls and minor liquefaction effects occurred within 10 km from the surface faulting and main shock epicentre.

Cape Fold Belt

$M_L 6.3$, Ceres, South Africa, 29 September 1969:⁴⁹ The most destructive earthquake in South African recorded history occurred on 29 September 1969 in the Ceres-Tulbagh region of the Western Cape, killing 12 people. Aftershock activity had virtually ceased, when a $M_L 5.7$ event occurred on 14 April 1970, causing further damage in the towns of Ceres and Wolseley. The maximum intensity was **VIII** on the Modified Mercalli Scale. The epicentral distribution of the aftershocks indicates fracturing along a near-vertical northwest-striking plane. The occurrence of this event was taken into consideration in the design and construction of the Koeberg Nuclear Power Plant near Cape Town.

Case Studies of Triggered and Induced Earthquakes

Mining-induced Seismicity

Mining-induced seismicity and its hazardous manifestation, rockbursting, were first encountered in South Africa in the early twentieth Century, when gold mines reached a depth of several hundred feet below the surface, with extensive excavation being supported solely by small pillars.⁵⁰ During the last century, thousands of mineworkers perished as a result of rockbursting in gold mines of South Africa. Damage to surface structures caused by two of the largest mining-related seismic events to occur in South Africa is shown in Figure 2.10. The largest earthquake to occur in a mining district in South Africa was a $M 5.5$ event that occurred on 5 August 2014 near Klerksdorp.



Figure 2.10: Effects of mining-related tremors in Welkom ($M_L 5.2$, 8 December 1976)⁵¹ and Stilfontein, South Africa ($M_L 5.3$, 9 March 2005).⁵²

Reservoir-induced Earthquakes

The impoundment of large reservoirs triggers local earthquakes, as a result of an increase in the surface load and the pore fluid pressure. A dam is a structure that contains tremendous forces, and failure of a dam wall could cause huge economic loss and have catastrophic consequences for downstream communities. The only reported incident of dam failure, as a result of an earthquake, is the failure of the 18 m-high earth-fill Fujinuma Dam in Japan, which was breached on 11 March 2011 during the 2011 Thoku earthquake. The 103 m-high rubble-concrete Koyna Dam in India suffered some cracks during a $M 6.5$ earthquake in 1967. Nevertheless, seismic hazard should be taken into account when designing any large dam, whether the seismic loading is due to natural tectonic earthquakes or reservoir-induced seismicity.

Lake Kariba, Zambia/Zimbabwe:⁵³ Kariba Dam on the Zambezi River was built in 1955-1959 and is one of the world's largest dams. Its wall is 128 m high, the reservoir is 280 km long and it has a storage capacity of 180 km³. The reservoir is located in a tectonically active branch of the East African Rift System. A $M_s 6.0$ earthquake occurred in the region in 1910. Seismic loading was not taken into account when designing the dam and no local measurements of seismicity were carried out prior to the impoundment (although many studies were carried out after 1959). Seismic activity increased as the dam filled and peaked in 1963. The largest earthquakes ($M > 5$) occurred in the vicinity of the dam wall. The largest event ($M_L 6.1$, which occurred in 1963) caused damage to the dam structure and some property in nearby settlements. No casualties were reported. Since 1963, there has been a general decline in seismic activity.

Katse Dam, Lesotho:⁵⁴ Seismicity has been associated with filling of the 185 m-high Katse Dam, which was completed in 1996. Seismicity was monitored from 1995 to 1999. The first recorded event took place when the water level in the

reservoir had risen by 45 m. The largest event had a magnitude of $M_L 3.0$, when fresh fissures opened along a shear zone adjacent to the dam and dwellings in the village of Mapeleng suffered minor damage.

Aswan High Dam, Egypt:⁵⁵ The 111 m-high Aswan High Dam, completed in 1970, has experienced significant reservoir-induced seismicity. The largest event to date occurred in 1981, recorded at $M_b 5.6$.

Mitigating Earthquake Risk

Reducing Earthquake Risk

A 'risk assessment' is an attempt to quantify the losses that could be caused by a particular hazard. Risk is commonly expressed by the following equation:

$$\text{Risk} = (\text{likelihood of the hazard occurring}) \times (\text{seriousness of consequences})$$

Given a certain level of ground shaking, the consequences of an earthquake depend on four main factors: the vulnerability of the buildings to damage; the exposure of people and other assets to harm; the cost of reconstruction; and the cost of lost economic production. Risk assessments are useful in raising awareness of possible disasters and motivating policies and actions to mitigate loss and avoid disasters. For example, vulnerable buildings may be reinforced, building codes enforced and insurance taken out to cover possible loss.

A 'disaster' is defined as any event that causes serious disruption, leading to widespread human, material or economic losses beyond the coping capacity of a given society. Disaster management agencies and non-governmental agencies (NGOs) provide short-term relief, while forensic investigation can provide valuable information that can be used to mitigate future occurrences. While many hazards are described as 'natural', consensus is emerging that very few disasters can truly be described as such because most disasters are due to the failure of a society to take adequate measures to mitigate the risks associated with known hazards.

Earthquake risk can be reduced by developing and implementing a national Disaster Reduction and Relief (DRR) strategy. Typically, the role and responsibilities of national, regional and local government, ministries and agencies are defined by law and require continuing action on several fronts. The components of a DRR strategy include:

- a) Monitoring seismicity and assessing the seismic hazard. These are usually the responsibilities of an agency such as the Geological Survey or Meteorological Office;
- b) Reviewing the vulnerability of the current housing stock and infrastructure (e.g. bridges and power stations) to seismic shaking. This information is combined

with the output of the seismic hazard assessment and the population distribution, and used to assess the seismic risk;

- c) Formulating building codes based on the risk assessment and their enforcement. The goal is to achieve minor repairable damage with minor shaking and to prevent collapse with strong shaking. Building codes in sub-Saharan Africa were recently reviewed by Worku;⁵⁶
- d) Reinforcing or demolishing structures that are deemed to be vulnerable, especially those that are occupied by many people (e.g. schools and offices) or that are critical in the case of a destructive earthquake (e.g. hospitals and emergency and rescue services);
- e) Insuring buildings and infrastructure against loss, either with commercial firms or through national schemes;
- f) Establishing and training disaster management agencies and emergency services. In addition, citizens should be encouraged to learn first aid, to join a community disaster relief team and to take practical steps to reduce the risk (e.g. avoid placing heavy objects on shelves, anchor tall and heavy furniture to walls, and check that escape ways are free of obstacles);
- g) Training the public to take appropriate action in the event of an earthquake; e.g. drop, cover your neck and head, hold on to a fixed object, hide in a safe place (such as under a table) and do not move until the shaking stops (Figure 2.11).



Figure 2.11: Poster showing the earthquake drill of: DROP, COVER and HOLD.⁵⁷

Progress towards managing earthquake risk in Ghana

Although the death toll of the 1939 earthquake that struck Accra was relatively small, Ghana has taken proactive steps to mitigate earthquake risks, which could serve as an example to other African countries. These are described here in some detail.

Historical catalogue and instrumental monitoring: A seismic catalogue for Ghana for the period 1615–2003 was compiled.⁵⁸ The four most destructive earthquakes to strike Ghana occurred in 1636, 1862, 1906 and 1939.^{59,60,61} The first seismograph was installed in 1914 and operated until 1933. Recording resumed in 1973

when a Worldwide Standard Seismograph Network (WWSSN) station was installed. A nine-station radio-telemetric network, with a central recording station in Accra, superseded this.⁶² The network is now fully digital.⁶³

Seismotectonic mapping and seismic hazard assessment: Geological studies have been conducted to identify active faults and the tectonic setting.^{64,65,66,67,68,69,70} The junction of the Coastal Boundary Fault and the Akwapim Fault Zone is the most seismically active area. These fault systems are an extension of the Romanche Fracture Zone, which extends from Brazil to Africa across the equatorial Atlantic region.⁷¹ A hazard map for Accra was published in 2009.⁷²

Risk assessment and mitigation: Bulletin No. 13 of the Gold Coast Geological Survey contains: a full account of the 1939 Accra earthquake;⁷³ a report on the geological effects, including recommendations for the rebuilding of Accra;⁷⁴ a seismological study;⁷⁵ and a discussion of the engineering aspects, including recommendations for the reinforcement of single-story block buildings.⁷⁶ However, a recent investigation of disaster risk preparedness,⁷⁷ which found an 'extreme laissez-faire attitude' towards disaster risk reduction in Ghana, highlighted the seismic risk to which the Greater Accra Metropolitan Area was exposed and appealed for the establishment of a mitigation-oriented disaster management programme.

Oteng-Ababio conducted a study of the Greater Accra Metropolitan Area,⁷⁸ and found that: the population increased nearly five-fold (340 000 to 1 660 000) between 1960 and 2000, mostly due to migration from rural areas; it could double again by 2020, if the growth rate of 4.2 per cent persisted. The pressure of development has overwhelmed planners and development has largely been haphazard. Owing to poverty, poor quality materials are often used. Building has frequently been incremental, which has made monitoring by inspectors difficult. Samples of sandcrete blocks were tested in the laboratory, in order to determine their strength, and building operations were observed. Interviews were conducted with practitioners, at both the national and local levels; and focus group discussions were held with residents, in order to gather information on the perceptions of urban hazards and the coping strategies. It was found that: developers tended to ignore the building code, which prescribes earthquake-resistant construction; many sandcrete blocks did not meet the standards. Multi-story buildings collapsed quite regularly, even in the absence of shaking, due to sub-standard construction practices. However, many residents did not believe that the disaster risk was serious and held the view that access to relief following a disaster would depend on political affiliation.

Strategies to manage earthquake risk in Accra are described by Oteng-Ababio. The National Disaster Management Organization (NADMO) was established, following promulgation of Act 517 of 1996. In 1997 NADMO drafted the National Disaster Management Plan (NDMP), which was reviewed in 2007. The plan is divided into three phases: (i) pre-disaster phase, involving prevention and mitigation; (ii) disaster or emergency response; and (iii) post-disaster recovery efforts. The National Standing

Operating Procedure for Emergency Response has been crafted, which identifies the role and responsibilities of government ministries, departments and agencies, and NGOs and volunteers. Ghana is considering the construction of a nuclear power station, which places even higher demands on seismic safety, and has commissioned a study to consider the issues involved in selecting a site.⁷⁹

Earthquake risk, the insurance industry and the FIFA 2010 Soccer World Cup

South Africa hosted the FIFA Soccer World Cup in 2010. To coincide with this event, the global reinsurance company, Aon Benfield, issued a report entitled *South Africa Spotlight on Earthquake* in conjunction with the Aon Benfield Natural Hazard Centre Africa.⁸⁰ The objective of the report was to enable insurers to obtain a more accurate estimate of their exposure and to motivate them to purchase appropriate reinsurance cover. The report states, '*Earthquake is the natural hazard that is most likely to trigger the largest financial loss in South Africa*'.

The Aon Benfield study assessed earthquake risk in Cape Town and Durban – cities where major new stadia had been built – which had experienced the largest seismic events recorded in South African history and where damage would most likely be greatest. The loss associated with a scenario earthquake, similar to the $M_L 6.1$ 1809 Cape Town earthquake, was considered. In the worst-case scenario, a $M 6.9$ earthquake on the Milnerton Fault would produce a Mercalli Magnitude Intensity of about IX or 'ruinous' in the Cape Town CBD and Cape Town Stadium, only 10 km away. Fortunately, the probability of such an event is low: of the order of 1 in 1 000 years. While a $M 6.3$ earthquake occurred near St Lucia, 220 km north of Durban, on New Year's Eve of 1932, Durban is not regarded as being exposed to high seismic risk, as no active faults are known to exist close to the city. The report concluded that a $M 5.0$ or $M 6.0$ event would only cause structural damage if the epicentre were closer than 45 and 90 km respectively. The return period of such events was estimated to be 735 and 5 000 years respectively.

Conclusions

During the twentieth Century, several African countries experienced deadly earthquakes that killed hundreds of people and caused significant economic loss. These countries include Algeria ($M_w 7.1$, 10 October 1980, 5 000 deaths), Egypt ($M_w 5.7$, 12 October 1992, 545 deaths), Ethiopia ($M_s 6.6$, 1 June 1961, 160 deaths), Guinea ($M_w 5.7$, 22 December 1983, 275 deaths), Morocco ($M_w 5.7$, 29 February 1960, 15 000 deaths) and Uganda ($M_s 6.0$, 20 March 1966, 150 deaths). Even a moderately sized earthquake can prove disastrous if it occurs beneath a city with many vulnerable buildings, as happened when: a $M_w 5.7$ earthquake struck Agadir, Morocco, in 1960; and a $M 7.0$ earthquake struck Port au Prince, in Haiti, in 2010. Historical records

indicate that events as large as M7.4 have occurred in the East African Rift System since 1900.

Earthquakes pose a significant risk in seismically active parts of Africa such as North Africa and the East African Rift System, especially as cities grow and many buildings are constructed without taking seismic hazard into account. While most earthquakes happen near plate boundaries, it should be noted that a damaging earthquake could occur anywhere in Africa. A low rate of seismicity does not mean that the maximum possible size of an earthquake is small – just that earthquakes are less frequent.

The mitigation of earthquake risk in Africa requires coordinated action on several fronts. It involves seismologists and geologists, civil and structural engineers, social scientists, national and local government, and NGOs that specialise in emergency relief aid.

Seismic hazard assessments should be improved by maintaining and expanding seismic-monitoring networks, supplementing historical and paleoseismic catalogues, and mapping active faults and the near-surface geology. Building codes should be formulated and enforced, and vulnerable buildings and infrastructure reinforced to prevent serious damage in a minor quake and collapse with severe shaking. Lastly, disaster management agencies, emergency first responders and the general public should: be trained to act effectively and sensibly during an earthquake; and equipped to deal with the aftermath.

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CHAPTER 3

Hazards and Disasters from the Eruptions of Volcanoes in Sub-Saharan Africa

Samuel. N. Ayonghe and Mabel N. Wantim

Introduction

Approximately 10 per cent of the world's population lives on or near one of the planet's 550 active volcanoes.¹ About 50 of the volcanoes exhibit some form of eruptive behaviour in any single year.² Less than a quarter of these active volcanoes are monitored although the monitoring is cursory at best – often just a single seismometer, or purely visual observation by inexperienced personnel or local inhabitants.

The topography and tectonic history of the African continent – from the extreme elevation of its southern craton to the plateaus and continental rifting in the north-east³ – set it apart from all other continental regions on Earth (Figure 3.1). The African tectonic plate covers the whole continent of Africa; the rift valleys of eastern and central Africa transect cratons, Precambrian orogenic belts and the oceanic lithosphere. The geology exhibits profound differences in: the volume and composition of magmatic products,⁴ the timing of rift initiation, the pre-rift plate structure and rift morphology.⁵ The continent is characterised by abundant Cenozoic intraplate volcanism, located mainly in non-cratonic areas, and distributed in northern, Central and East Africa (Figure 3.1).⁶ This volcanism appears as discrete centres or linear zones, most of which are associated with domal uplift of the basement.

Africa has the highest percentage of volcanoes that are undated but known to be Holocene. The distribution of dormant and active volcanoes on the continent (Figure 3.1) is indicative of the concentration of active volcanoes in two major zones: the East African Rift Valley System (Figure 3.2) and the Cameroon Volcanic Line (CVL) in central Africa (Figure 3.3). The development of the East African Rift System (EARS) during the last 20 million years (caused by tectonic rifting) supposedly influences the regional climate in Africa.⁷ This scenario highlights the increasing requirement for successful forecasting of volcanic phenomena and reveals the need for a contemporaneous increase in the general level of surveillance. Most African volcanoes result from hotspots, rifting, or a combination of the two.

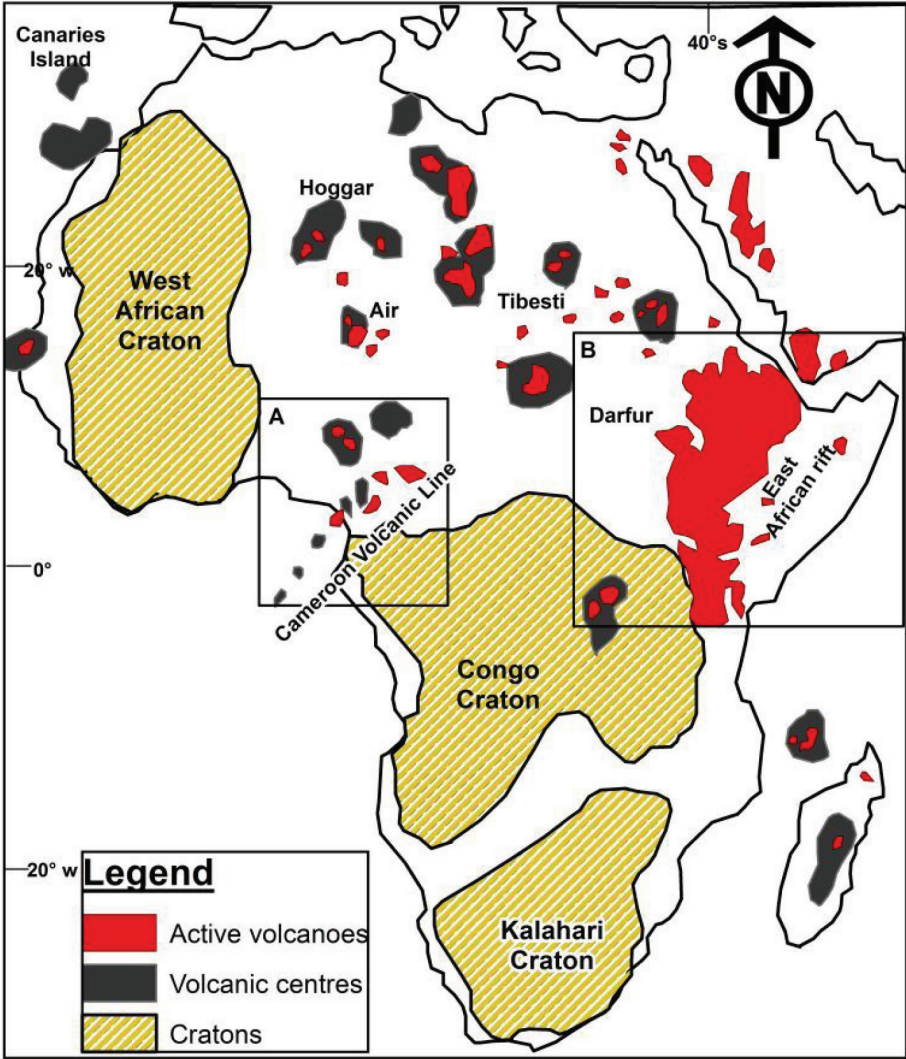


Figure 3.1: Map showing African cratons, zones with presently active volcanoes, and the Cameroon Volcanic Line (A) and the East African Rift System (B).

Hazardous phenomena generated during volcanic eruptions have claimed over a quarter of a million lives since the beginning of the eighteenth Century: 78 000 since 1990; and approximately 30 000 over the past 15 years alone.⁸ Many tens of millions of lives have also been disrupted as a result of volcanic activity through enforced evacuation, starvation, disease, damage to the local environment, and disruption of the social and economic fabric. Regardless of improvements in monitoring technologies, the rapid population growth where most active volcanoes are located has ensured an increase in the vulnerability of the populations and their property to the active volcanoes during the twenty-first Century.

Improvements in eruption forecasting are critical for combating this situation, for reducing injury and loss of life and for minimising the detrimental effects on local economies and on the fabric of society.⁹ However, basic information about the character of past volcanic activity is lacking for most of these active volcanoes on the continent, where priority is most often given to alleviating poverty and combating disease, rather than monitoring and mitigating adverse impacts of volcanic activity.

The East African Rift System

The EARS is one of the major tectonic structures of the Earth. It extends for about 6 500 km, from the Middle East (Dead Sea-Jordan Valley) in the north, to Mozambique in the south, and is characterised by a series of fault-bounded depressions (Figure 3.1). This system consists of three main arms: the Red Sea Rift; the Gulf of Aden Rift; and the East African Rift (or Ethiopian Rift/Afar Depression), which develops through Eritrea, Ethiopia, Kenya, Tanzania, Zambia, Malawi and northern Mozambique and which is floored by a thinned continental crust.^{10,11} It is composed of two rift trends or branches: the eastern and western branches. The Eastern Rift extends from Eritrea and Djibouti to northern Tanzania and traverses five (e.g. Rwanda and the Democratic Republic of Congo (DRC)) other countries.¹² The western branch develops in Uganda and extends through Lake Tanganyika southward to Malawi and through seven countries, to join the eastern branch, following the border between Rwanda and the DRC.^{13,14} The western branch is much less active in terms of volcanism, although both branches are seismically and tectonically active today (Figure 3.2).

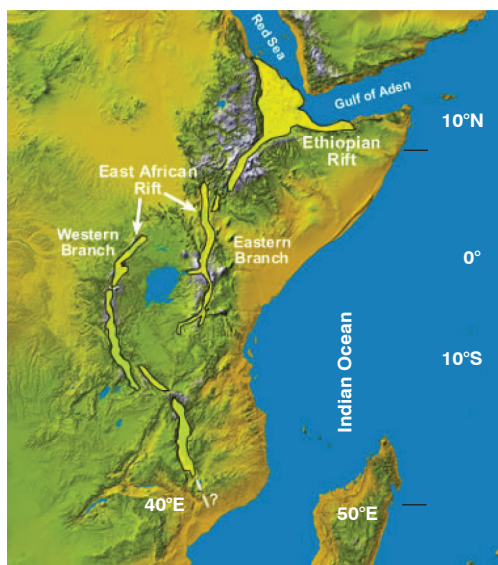


Figure 3.2: Space shuttle radar topography image (NASA) showing the East African Rift System (EARS) and its branches. The names given to the main rift segments change, depending on the source.

Tanzania is the only country that hosts both rifts (eastern and western). The rifts include a number of the following active and dormant volcanoes: mounts Kilimanjaro, Kenya, Longonot, Menengai Crater, Karisimbi, Nyiragongo, Nyamulagira, Meru and Elgon, as well as other highlands in Tanzania. In Kenya, the EARS hosts 12 Quaternary volcanoes that lie along its central rift axis.¹⁵ The Oldoinyo Lengai volcano in Tanzania remains active and is currently the only natrocarbonatite volcano in the world.¹⁶ Volcanic fields in western Uganda, with altitudes ranging from 900 to 1 500 m above sea level (a.s.l.) and extreme lows (600 m in the rift) and highs (5 100 m in the Rwenzori Mountains), mark the northernmost magmatic activity in the western branch of the EARS.^{17,18} Rift sectors in the Eastern Rift (Tanzania-Ethiopia), southern Red Sea, Gulf of Aden and parts of the Western Rift are marked by active volcanoes and fissures.¹⁹

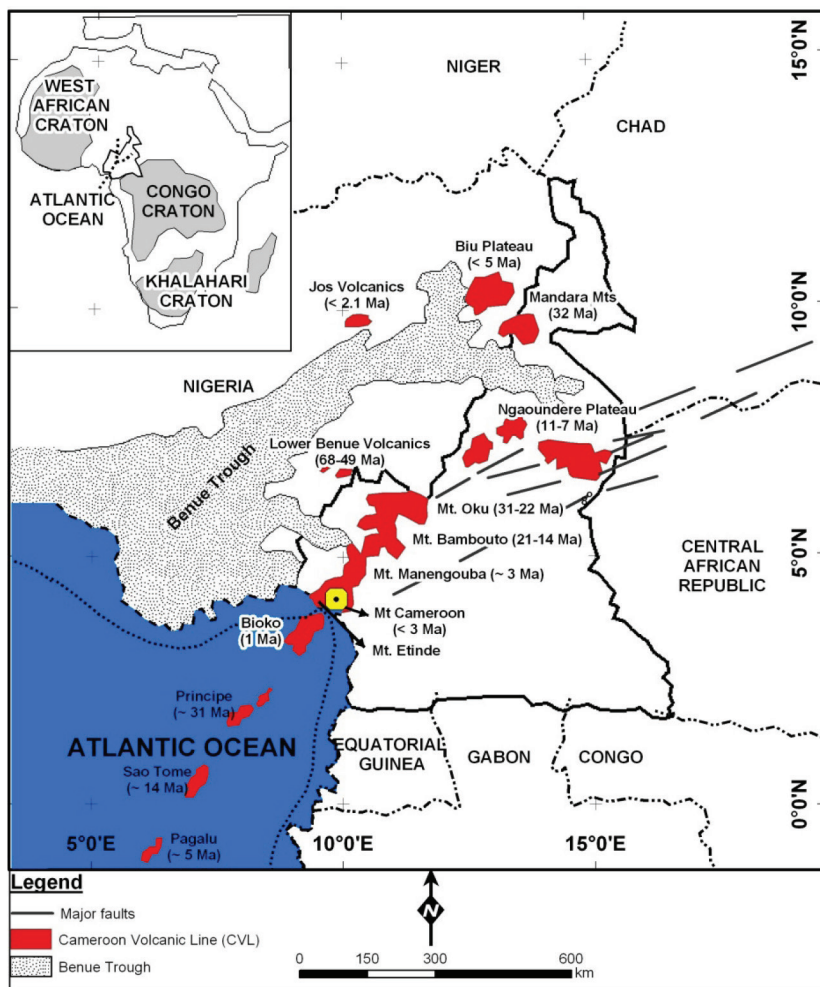


Figure 3.3: Sketch map of Cameroon showing Mount Cameroon and the Cameroon Volcanic Line (CVL). Inset is the CVL and Cameroon within the African continent.

The Ethiopian Rift System

Ethiopia has a unique location. It is at a tectonic triple junction that comprises the Red Sea, the Gulf of Aden and the Main Ethiopian Rift (MER) (Figure 3.2),²⁰ where volcanic and tectonic activity have occurred since 30 Ma.²¹ The Red Sea and the Gulf of Aden are incipient oceans, with prominent spreading zones, while the third branch – the Ethiopian Rift – is the beginning of a large system of depressions that extend along the African continent, first to the southwest and then to the south.²²

The Ethiopian Rift Valley was first outlined as a tectonic unit by Oscar Neumann in 1909.²³ It contains a wealth of geological features and shows much evidence of recent and ongoing geological activity in the form of young volcanoes, fresh fault scarps, steaming vents, pulsing hot springs and occasional earthquakes.²⁴ Several volcano-tectonic events have occurred in Afar and the MER during the last 20 years, notably: in 2000, 2003/2004; and the Dabbahu-Manda-Hararo sequence that has been active since September 2005,²⁵ with volcanic eruptions and seismic tremors being recorded.²⁶ The principal hazard from this rift is earthquakes (seismic swarms), with a magnitude of ≥ 5 associated with volcanic activity in all sectors of the rift.

The main geological features of the Ethiopian Rift Valley are: a line of volcanic cones (Gedamsa, Bericha, Borra, Alutu, Shala, Chabbi, etc.) (Figure 3.4); and associated fault scarps that run the length of its floor (Figure 3.4). These volcanoes may be classified as dormant since their most recent eruptions occurred hundreds or thousands of years ago. These volcanoes may erupt again in the not-too-distant future, given the presence of steaming fumaroles and hot springs on the rift floor. These volcanoes have erupted a variety of products, including: lava with a rhyolitic composition that results in obsidian (black glassy rock) in some cases; ash; ignimbrite (rock deposited from nuée ardente); and pumice.²⁷

The Ethiopian Rift Valley is dissected by hundreds of young faults that are concentrated into a narrow belt that runs almost parallel to the Rift margin faults. They are known as the Wonji Belt fault (Figure 3.4) and they mark the most active section of the Rift Valley.²⁸ Most of the Rift Valley earthquakes have their epicentre within this fault belt. The entire pattern of volcanoes and faults in the Rift Valley indicates a thin underlying crust that is being pulled apart by east-west forces. Sediments and sedimentary rocks form a cover over much of the ignimbrite on the Rift Valley floor (Figure 3.4).

The Afar triple junction (ATJ) is a transition case from continental rifting to oceanic spreading.²⁹ Afar and the MER host several active volcanoes and fissure eruptive centres, which can potentially pose a hazard to human life and development activity in the region.³⁰ There have been numerous volcanic eruptions in the Afar-Red Sea region since the onset of the Manda Hararo rifting event in 2005, including effusive basaltic fissures, lava lake overflows and ash-rich plumes.³¹ Most of these eruptions occurred in remote areas, which means that eyewitness reports and direct measurements are scarce.

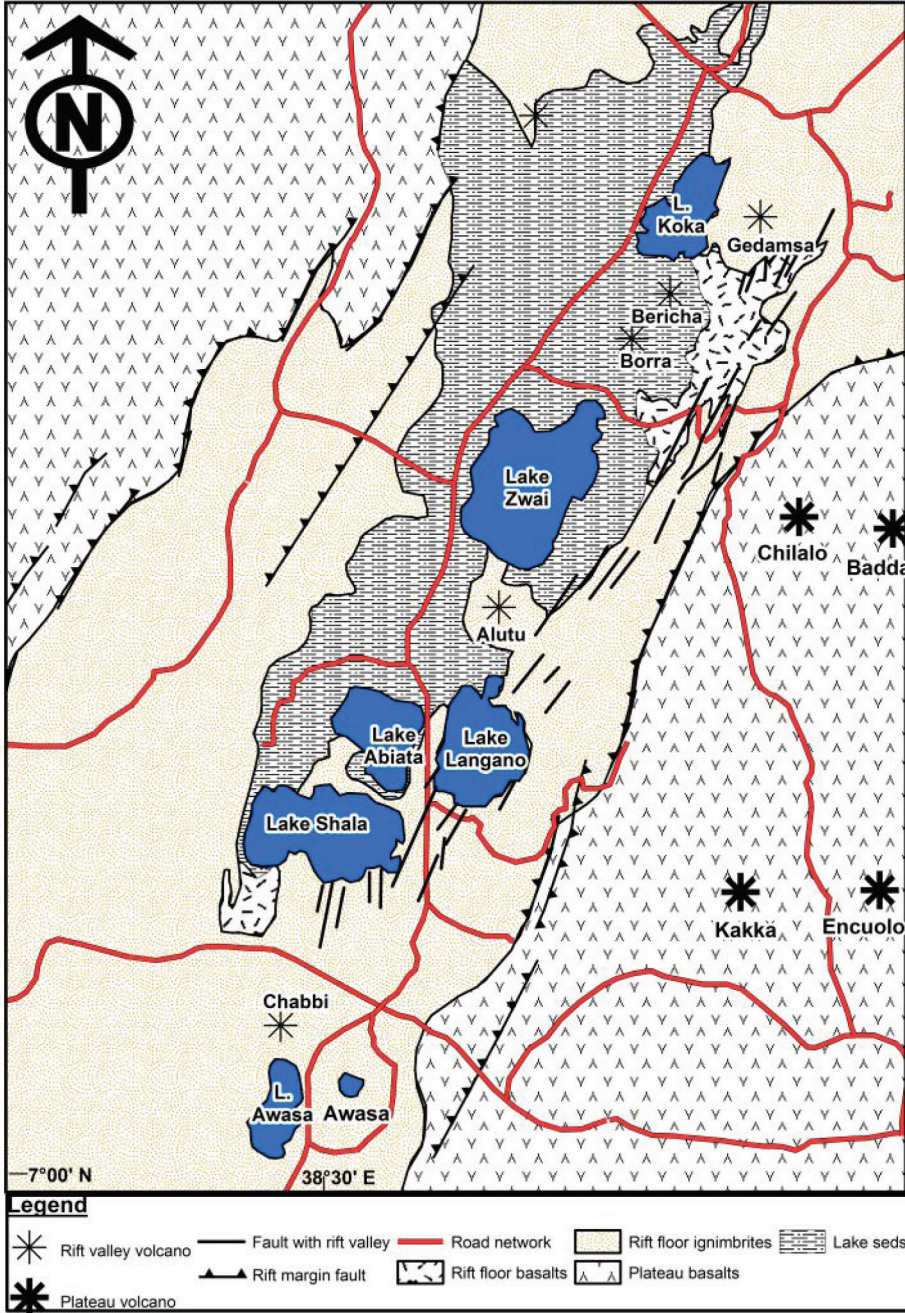


Figure 3.4: Geological sketch map of the Central Ethiopian Rift (modified from Williams and Mohr, 2011).

The MER has experienced significant volcanism, and the mantle beneath is characterised by high temperatures and partial melt.³² Recent studies using satellite-based Interferometric Synthetic Aperture Radar (InSAR) observations demonstrate that

significant deformation occurred at four volcanic edifices in the MER (Alutu, Corbetti, Bora and Haledebi) from 1993 to 2010.³³ This has raised the number of volcanoes known to be deforming in East Africa to above 12, despite the small number of recorded eruptions. InSAR has the ability to characterise ground deformation in all atmospheric conditions which is relevant to detect and understand periods of volcanic unrest.

In the absence of detailed historical records of volcanic activity, satellite-based observations of monitored parameters, such as deformation and gas content, have played a significant role in assessing volcanic hazard from these volcanoes. For example, during the ongoing Afar rifting episode that began in 2005, satellite observations of sulphur dioxide (SO₂) emissions by the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite played a key role in eruption detection and monitoring.³⁴ Detection of SO₂ emissions has often been the first indication of an eruptive event, typically followed by thermal infrared (IR) manifestations of active lava effusion. Since 2005, SO₂ emissions associated with eruptions in Afar have ranged from low or undetectable (e.g. Dabbahu and Manda Hararo) to among the largest volcanic SO₂ emissions measured since the 1990s (e.g. 2011 Nabro eruption), reflecting the variability in eruption style and magnitude.

Volcanism within the Afar Depression is strongly bimodal,³⁵ which implies associated basaltic and silicic volcanism. Silicic magma forms when mafic magma stalls in the shallow crust and erupts either explosively (to generate ash falls and flows) or effusively (to produce lava flows and domes).³⁶ A silicic explosive eruption from Dubbi Volcano (Ethiopia) in 1861: deposited ash more than 300 km from the volcano; destroyed two villages; and caused more than 100 fatalities. Similarly, in 2005, silicic eruption from Dabbahu Volcano (Ethiopia) produced ash and a small pumice cone, and forced the evacuation of more than 6 000 people from nearby villages.³⁷ Dabbahu is a composite volcano at the north end of the active Manda-Hararo segment of the Afar Rift.³⁸ Dabbahu has erupted magma types that range in composition from mildly alkaline basalt to trachytes and rhyolites. Effusive eruptions predominate from this volcano.³⁹

The Danakil Depression is the most important volcano-tectonically active portion of the Afar region and the EARS. In its centre are several volcanic edifices, which constitute seven major shield volcanoes.⁴⁰ Dallol Volcano is located in the Danakil Depression in the northern part of the Afar triangle on the north-northwest-trending active Erta Ale axial segment, which hosts a number of active volcanoes, including the perennial lava lake of Erta Ale.⁴¹ It is elliptical in shape, rises gently to 60 m from the salt plain (-48 m a.s.l.) and was the site of a phreatic eruption in 1929. The Dallol Volcano vicinity is characterised by frequent earthquakes of magnitude 4.5-5.5 on the Richter scale.

The Dallol Crater hosts a number of active and fossil hot-springs, geysers and fumaroles, which have formed a colourful mosaic of salt deposition and acid pools

inside the crater.⁴² Artisanal rock salt mining in the region has resulted in a permanent settlement at Ahmedela town, near Dallol. Residents of Ahmedela town observed unusual dark-coloured smoke from Dallol Crater in the first week of January 2011. This event was not strong enough to be recorded by global volcano-monitoring satellites. Observations of remnant ash and sulphur deposits at the site suggested degassing of a near-surface volcanic vent. The geodynamic setting of Dallol Volcano suggests that, besides earthquakes, phreatic and (probably) phreato-magmatic eruptions are the prevailing geo-hazards.⁴³

Erta Ale Volcano, which is 50 km wide, with a height of more than 600 m a.s.l., descends to -120 m below sea level, has a base diameter of 30 km and is found in the north of the Great Rift Valley in the Danakil Depression. It could be considered one of the most active volcanoes in Ethiopia.⁴⁴ Erta Ale means 'Smoking Mountain' in Afar. Its principal hazard is basaltic lava flows that issue from fissures. Long-term lava lakes (active since 1965) are common at the summit caldera. Recent fissure eruptions have occurred on the northern flank of Erta Ale. In the Erta Ale Magmatic Segment (EMS), a large basaltic eruption occurred at the Alu-Dalafilla range in November 2008 and the Erta Ale lava lake itself overflowed in November 2010.⁴⁵

Recently, 65 Holocene volcanoes were identified in Ethiopia; 34 of them have been classified as predominantly effusive (production of lava flow) and the remainder have been recorded as having delivered significant explosive eruptions.⁴⁶ No explicit eruptive history exists for 49 of Ethiopia's 65 volcanoes. As such, under-reporting may downplay the level of hazard posed by eruptions both in the past and in the present. Historical records indicate about 160 fatalities in three eruptions, with the greatest loss of life being in Dubbi in 1861. An estimated population of more than nine million people lives within 30 km of an active volcano in Ethiopia, but these volcanoes yield low- and medium-hazard levels.⁴⁷

Using the population exposure index, five of these volcanoes classify as high risk: Bilate River Field, Bishoftu Volcanic Field, Butajiri-Silti Field, Corbetti Caldera and Hobicha Caldera.⁴⁸ This analysis undoubtedly underestimates the number of high risk volcanoes, due to poor baseline geological and hazard knowledge. Return periods of explosive eruptions in Ethiopia are estimated to be between seven and 100 years. Recent studies (from field and satellite sensors) that were carried out on the entire Ethiopian Rift have led to a remarkable understanding of this rift system, although these studies have left several questions unanswered.⁴⁹ The major hazards associated with these Ethiopian volcanoes are earthquakes and lava flows, with significant quantities of ash on rare occasions.

Northern Afar Triangle: Danakil Depression (Eritea)

The Danakil Depression, or Northern Afar Triangle, is a region of active volcanism. This depression is a sub-aerial segment of the spreading system that opens to form the Red Sea.⁵⁰ The northern Danakil Depression lies near or below sea level for much

of its extent. It is surrounded by the Danakil horst (Alps) to the east and the Eritrean plateau or highland to the west.

The Alid volcanic centre, Eritrea, is located along the axis of the Danakil Depression.⁵¹ Its eruptions produce principally rhyolitic magma and pyroclastic deposits. Fumaroles and boiling pools are distributed widely on the northern half of Alid. The wide distribution (10 km²) of fumaroles on the northern half of Alid indicates that a relatively large heat anomaly exists beneath the volcanic centre, which represents a potential source of hazards.

Nabro Volcano, in the northern Red Sea region of Eritrea, began erupting explosively (its first eruption in recorded history) in June 2011.⁵² This stratovolcano is one of many volcanic caldera complexes in the extreme northeastern part of the East African Rift valley region. It is located in the Danakil Depression, close to Eritrea's border with Ethiopia and north of Djibouti, and had not previously erupted in at least 150 years. The 2011 Nabro Volcano eruption released an estimated ~2 Tg or more of SO₂. The gases released from this eruption affected aviation and caused a significant stratospheric aerosol perturbation that was detected worldwide by ground-based Light Detection and Ranging Radiometer (LIDAR) instruments.^{53,54} Eruptions (sub-plinian/plinian) from this volcano continued until mid-July 2011. These recorded satellite observations enabled reliable alerts to be transmitted to local and national authorities, before eye-witness reports were communicated. The eruption of the Nabro Volcano was the seventh eruption in Afar in less than six years.⁵⁵

Djibouti Western Rift

The Republic of Djibouti lies at the junction of three active, major coastal spreading centres: the EARS; the Gulf of Aden Rift; and the Red Sea Rift.⁵⁶ The country is dominated by plateaus, plains and mountainous portions and separated by the Gulf of Tadjourah ridge.^{57,58} This region is the western-most segment of the Gulf of Aden (south-east Afar margin). It is characterised by numerous past and current hydrothermal events located: in specific zones of the western region (formed by the opening of the Afar and Danakil depressions); and to a limited extent in the eastern part, around the Gulf of Tadjourah ridge,⁵⁹ which is affected by the Afar hotspot.⁶⁰ In November 2010, a significant volcanic-related swarm of seismic events of magnitude 5.6 occurred along the westernmost sector of Aden.⁶¹ It was the most significant in recent years and affected the spreading ridge in the EARS.

The North Tanzanian Divergence Zone (NTD)

This area is currently volcanically active, with a magmatic history that initiated in the Miocene epoch.⁶² Some of the NTD volcanoes are among the Earth's largest (e.g. Kilimanjaro and Ngorongoro) (Figure 3.5). They have produced a diverse array of lava, from basalt to rhyolite, trachyte, phonolite and carbonatite (as seen on

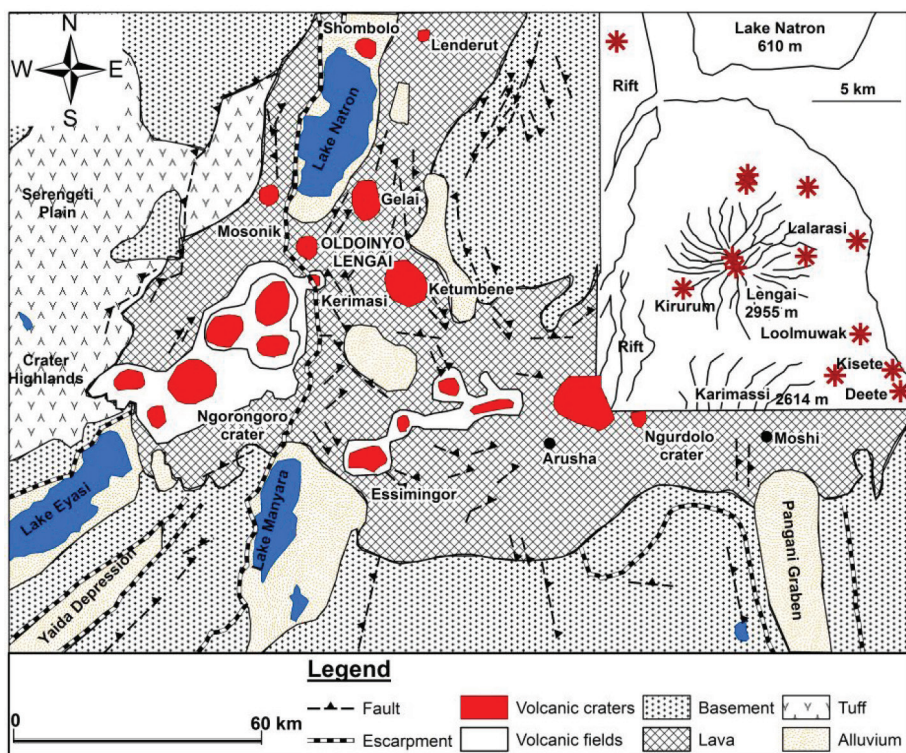


Figure 3.5: Regional geological context of the northern Tanzanian section of the EARS. Inset is a sketch map of the Lengai area (modified from Kervyn et al., 2008).

Kerimasi and Oldoinyo Lengai volcanoes).^{63,64} The oldest NTD magmatism (5.9 Ma) was recorded at the centrally located Essiminingor Volcano.⁶⁵

Oldoinyo Lengai (OL), found in the northwestern part of Tanzania (tectonically active region) (Figure 3.5), is a pyroclast-dominated stratovolcano with volumetrically minor intercalated lava flows.⁶⁶ OL is one of four carbonatite volcanoes in the region, the other three being Shombole, Mosonik and Kerimasi. Kerimasi, located southeast of OL (Figure 3.5), is the youngest active volcano in northern Tanzania, the most active volcano along the NTD and one of the most active volcanoes in Africa. It is a steep stratovolcano with an elevation of 2 962 m a.s.l. Its eruptions are characterised by cycles of effusive and explosive volcanism that result in the release of ash, carbonatite lava flows (extremely fluid lava flows at relatively low temperature), volcano collapse and debris avalanches (caused by the failure of unstable volcanic edifices, commonly triggered by an eruption). It has been continuously active since 1983 (1993, 2005, 2006 and 2007-2008), with the activity confined to small-scale effusive and explosive eruptions of natrocarbonatite lava within the summit crater. It is the only volcano on Earth that emits natrocarbonatite lava.⁶⁷ During the twentieth Century, OL underwent several explosive eruptions: in 1917, 1940-1941 and 1966-1967.

From a hazard perspective, volcano collapse (which initiates debris avalanches) and rapid lava emplacement from OL pose a threat to tourists and the local population. Volcano collapse is presently recognised as one of the major hazards at OL.⁶⁸ It is among the most destructive and hazardous volcanic events, producing debris-avalanches that can travel at initial velocities of up to 100 ms^{-1} and cover extensive areas. At the end of 2007, it was also observed that the ash emitted from these episodic explosive eruptions adversely affected the local Masai population and aircraft.⁶⁹ Other older explosive eruptions from OL have also affected the local population, cattle, wildlife, and local and international air traffic.^{70,71}

The Virunga Volcanic Province

The western branch of the EARS (Figure 3.6) is formed by a succession of rift basins linked by transfer zones. These zones are characterised by volcanic provinces and faults. This is the case for the Virunga Volcanic Province (VVP), which is located between Lake Edward basin (in the north) and the Lake Kivu Basin.⁷² The Kivu Basin is a 100 km-long segment of the western branch of the East African Rift, bordered respectively to the north and south by the VVP and the South Kivu Volcanic Province (SKVP).⁷³ Volcanism in the SKVP is considered extinct, but seismicity remains an important threat to the population, as was portrayed by the 2008 earthquakes' sequence that killed about 40 people in the Bukavu and Cyangugu regions.⁷⁴

Nyamulagira, one of Africa's most active volcanoes, is a 3 058 m high shield volcano with a 2-2.3 km caldera. It is located south of the Virunga National Park in the southeastern part of North-Kivu, DRC.⁷⁵ It is presently the most active volcano in Africa with, on average, one eruption every 2-4 years.⁷⁶ It is one of the two active volcanoes in the VVP (Figures 3.6 and 3.7) and it has erupted over 19 times since 1965.⁷⁷ Its most recent eruptions took place in 2010 and 2011.⁷⁸ Principally, it releases basic lava flows with low viscosity that flow for tens of kilometres before halting.⁷⁹

Hazards that result from this volcano have been assessed as posing a non-negligible hazard for the local population and the environment.⁸⁰ However, there have been no reported cases of direct casualties from its hazards, unlike at Mount Nyiragongo, the second active volcano in the VVP, with two historic eruptions (1977 and 2002) over a span of 100 years. These eruptions are also the only known cases in the world where people were killed by lava flows. The 2002 eruption lasted for just one day, with 15 per cent of Goma city destroyed and with nearly 150 people (mostly children) killed and about 300 000 people displaced.⁸¹ Fast lava flows destroyed the city of Goma and created a humanitarian crisis with a socio-economic impact that is still visible today.⁸² The 2002 eruption also represents one of the very rare cases of direct casualties from lava flows.

Nyiragongo still hosts (in its crater) what is currently the largest semi-permanent/permanent lava lake on Earth (approximately 200 m wide). The magma level

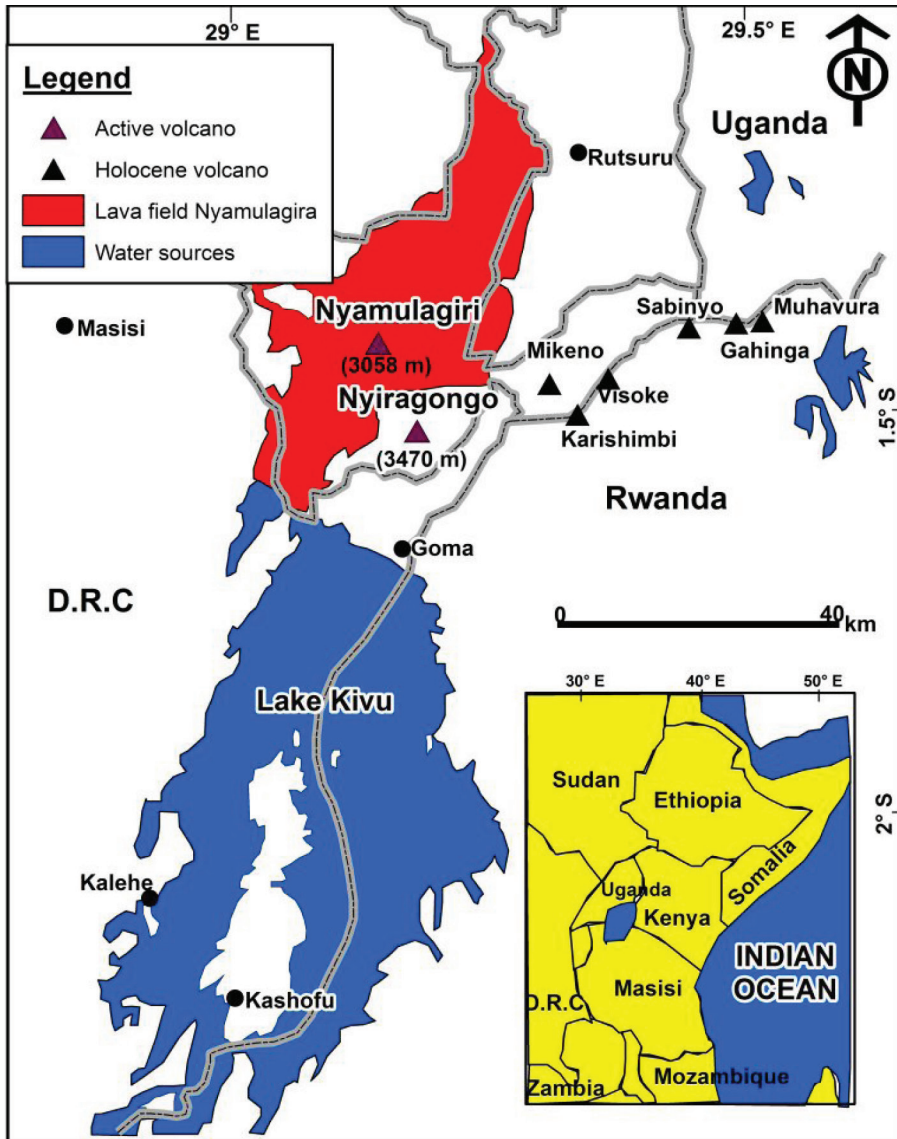


Figure 3.6: Location of Nyamulagira, Nyiragongo and the VVP. Inset is a map that shows countries within the EARS (modified from Smets et al., 2010).

in the open conduit of this lake rises up to tens of metres per year, increasing the edifice's instability and the amount of molten lava in the crater.⁸³ It is possible that a new eruption, similar to the 2002 event, could lead to a major disaster, with severe social and economic impact for the Great Lakes Region of Central Africa.⁸⁴ A lava flow hazard map produced by Favalli et al. shows the eastern sector of Goma, which was devastated by the 2002 event, as the highest hazard zone on the flank of the volcano.⁸⁵

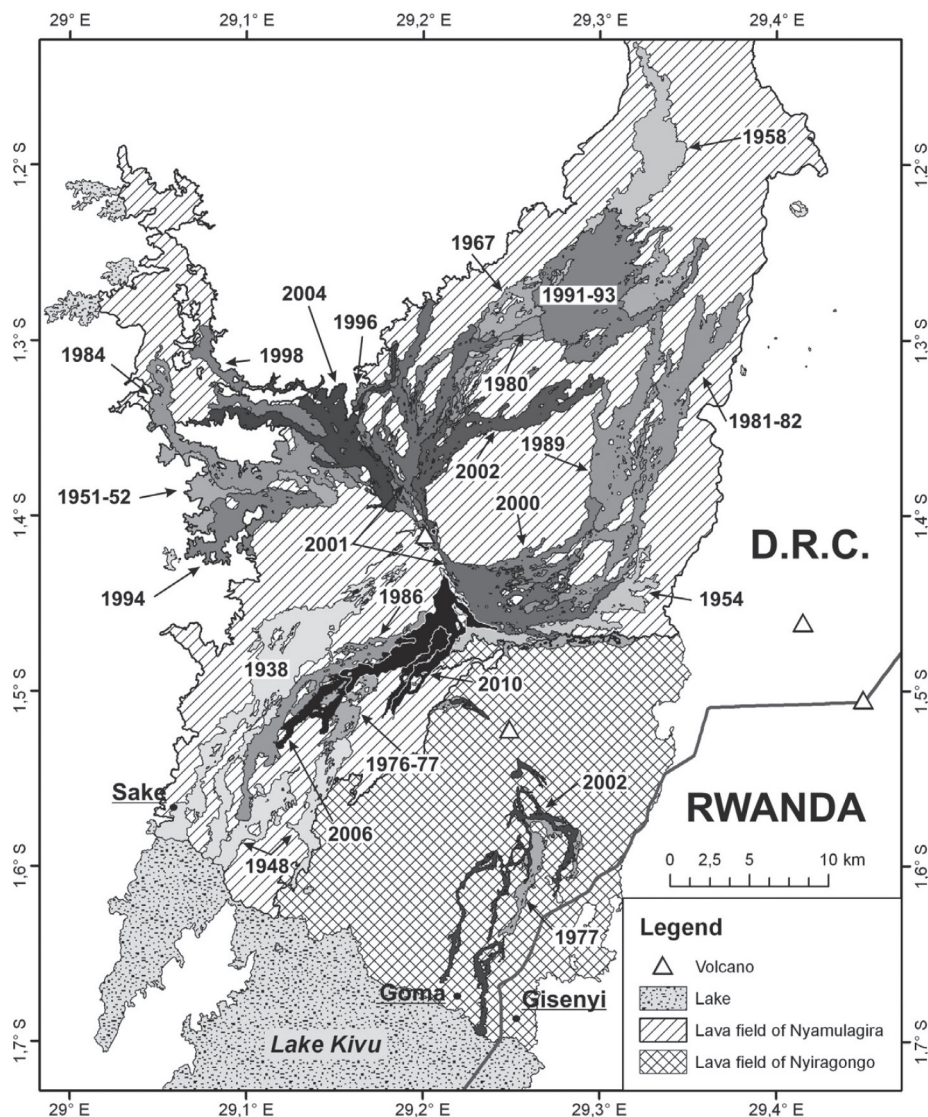


Figure 3.7: Map of most recent (1938–present) lava flows from Nyamulagira. (The darker flows are the most recent.) The Nyiragongo lava field is also identified with its two most recent flows, from the 1977 and 2002 eruptions (Smets et al., 2010).

Karisimbi Volcano (Rwanda) is part of the Virunga volcanic field; it is the highest (4 506 m a.s.l.) and one of the largest of the eight major volcanoes in the Virunga volcanic field.⁸⁶ Unlike the Nyiragongo and Nyamulagira volcanoes, Karisimbi is not active, although neighbouring Visoke had a brief eruption in 1957.⁸⁷ The principal hazard released from this volcano is lava flows, which range from basalts to trachytes.

The Cameroon Volcanic Line (CVL)

The CVL is a major tectonic feature in West-central Africa that runs southwest-northeast following a major left-lateral fault system that extends for more than 2 000 km, from Pagalu Island into West-central Africa (Figure 3.3). It is also referred to as the 'Cameroon Line'^{88,89,90,91,92} or the 'Cameroon Hot Line'.⁹³ Half of this line lies in the Atlantic Ocean and the other half on the African continent (Figure 3.3). The continental part of the CVL splits into two main branches at the northern end, running into northeast Nigeria (Biu Plateau) and the Ngaoundere Plateau (also called the 'Adamawa Plateau') (Figure 3.3).^{94,95} The oldest dated volcanic rocks along the oceanic sector of the CVL range in age from 15 to 35 Ma,⁹⁶ while in the continental sector the rocks range from 9 to 34 Ma (Figure 3.3).

The continental segment of the CVL

The continental segment of the CVL includes mounts Cameroon (MC), Etinde, Manengouba, Bambouto, Oku and Mandara, as well as the volcanic provinces of Biu and Ngaoundere Plateau (Figure 3.3). Volcanic activity along the CVL dates back to about 30 Ma.⁹⁷ Presently, volcanic activity along the CVL is restricted to eruptions of basaltic lava at: Pico Santa Isabel (1898, 1903 and 1923) on Bioko Island; and at Mount Cameroon, where seven eruptions were recorded between 1909 and 2000.⁹⁸ The whole of the continental substratum is covered with Cretaceous to Pliocene-Quaternary sediments (mostly found in coastal areas), upon which the lava of MC and the Manengouba, Bambouto and Oku mountains accumulates.⁹⁹ All the volcanic rocks along the CVL are typically alkaline, with the exception of those at Mount Etinde,^{100,101} which span the whole cycle of the differentiated alkaline series: basaltic lava, intermediate lava and felsic lava.

Mount Cameroon (Figure 3.8), which is about 4 095 m high, is the largest active continental volcano along this line, based on its recorded historical eruptions during the twentieth Century and twenty-first Century (1909, 1922, 1954, 1959, 1982, 1999 and 2000). It hosts a population of over 350 000¹⁰² on its flanks and is covered by a succession of lava flows^{103,104} and approximately 340 mapped scoriae cones (Figure 3.8). Based on recorded eruptions, this volcano exhibits two eruption styles: effusive and explosive. The quiet extrusion of basaltic lava from both the summit and flank vents is usually accompanied by: earthquake swarms/tremors (pre, syn and post), with intensities of IV-VII on the maximum Modified Mercalli Intensity Scale; the exsolution of gases from fumaroles; and the release of tephra into the atmosphere.^{105,106,107,108,109,110,111,112,113}

The frequency of eruption in the past century presents MC as an active volcano with no definite quiescent period. With the exception of the summit eruption of 1954, which was highly explosive but produced no lava flows, the other eruptions of MC in the last century have all created a variety of volcanic phenomena, dominated by suites of extensive basaltic lava flows, seismic swarms, ash, and tephra deposits.

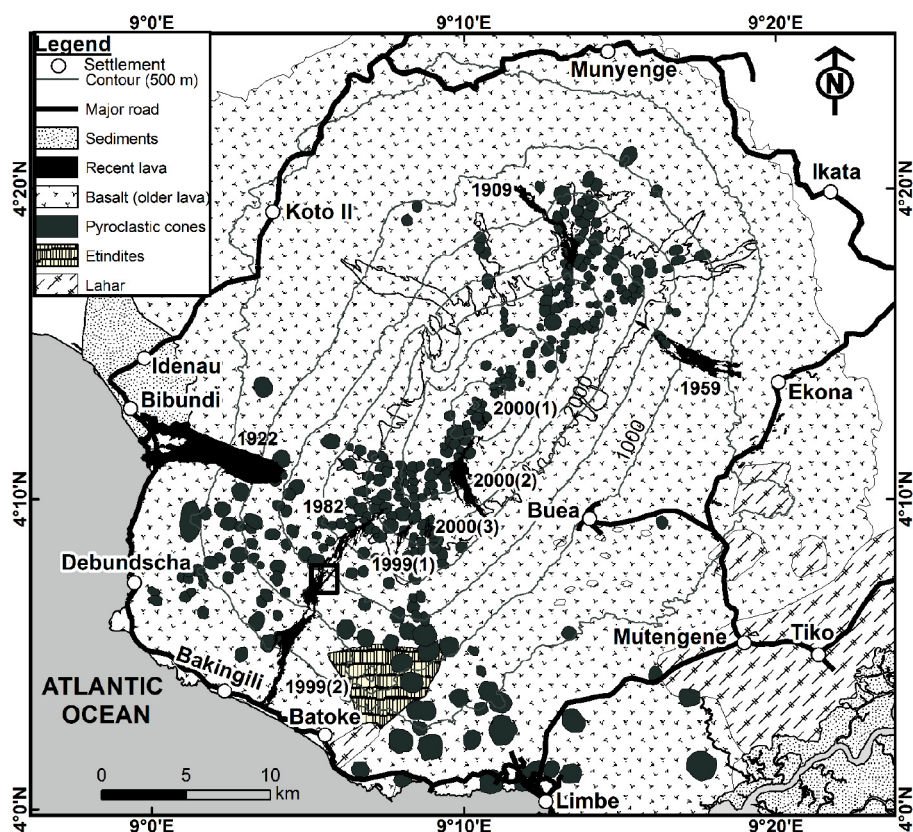


Figure 3.8: Geologic map of Mount Cameroon Volcano and surroundings, showing the 20th Century and 21st Century lava flow fields and scoria cones (~ 340).

Earthquakes and lava flows from the 1922, 1959 and 1999 eruptions posed major threats to agro-allied complexes and infrastructure around the southwest, southeast and northeast flanks of the mountain.^{114,115,116,117} Ash released during the 1999 eruption affected the population on the southwest flank of the volcano.

The oceanic sector of the CVL

The oceanic sector of the CVL is composed of six major volcanoes found on four major islands: one each on Pagalu, the Sao Tome and Principe islands; and three on Bioko Island (Figure 3.3). The sub-aerial part of Bioko is basaltic, with no record of other evolved rock types. The island has three main central volcanoes: San Carlos and Pico Biao (both in the south) and Santa Isabel, located to the north, which is the most active volcano on the island and known locally as 'Pico Basile'.¹¹⁸ Unlike MC, for which some documentation on its historical eruptions exists, even though this is scanty, little is known about the Bioko eruptions, such as the last that occurred on the southeast flank of Santa Isabel Volcano in 1898.

Problems and Options related to Mitigation and Prevention

The foregoing analysis suggests that hazard and disaster perspectives of the active volcanoes on the continent are indicative of increasing vulnerability of the populations around these volcanoes. Examples of vulnerable populations are those that have settled to cultivate the fertile volcanic soils on the flanks of active volcanoes or simply prefer to live in the favourable climatic conditions around the volcanoes (such as in Cameroon), people mining rock salt (such as in Ahmedela town in Ethiopia), and those involved in harnessing geothermal energy (such as in Kenya and Ethiopia).

Some volcanoes manifest bimodal behaviour, with an initial silicic explosive eruption from which ash falls and destroys villages located hundreds of kilometres from the volcano prior to the commencement of effusive basaltic flows.^{119,120} High population concentrations around some volcanoes (e.g. about one million people threatened by the Nyamulagira and Nyirangongo volcanoes and over 350 000 people, including those at the University of Buea and several agro-industrial complexes, threatened by MC) increases human vulnerability. Vulnerability is also related to the past frequencies of eruptions of volcanoes, such as Mount Nyamulagira, which erupted 30 times during the last century; MC, which has had a quiescence period of about 16 years; and volcanoes in Ethiopia with return periods of explosive eruptions of seven to 100 years.

Human responses to the volcanic threats are influenced by many factors, such as culture, belief systems, education, awareness, trust (or lack of trust) in experts and authorities, indigenous knowledge and past experiences. Therefore, approaches to risk reduction will have to be limited to improvement in scientific knowledge regarding the physical hazards, monitoring capacity, ability to give early warning, and human behaviour and controls regarding societal resilience during disasters.

In fact, the resilience of populations living around volcanoes depends on many factors, but two generalisations can be made.¹²¹ Where eruptions are infrequent (in some cases the last eruption predates societal memory), it can be difficult to get a community to understand the meaning and nature of the incipient risks and to accept that mitigation measures may be necessary. Mitigation and prevention of the risk posed by natural hazards have not attracted widespread and effective public or political support in the past, but wide media attention paid to major natural disasters has dramatically changed the situation during the past decade, and it is now generally accepted that a proactive approach to risk management is instrumental in significantly reducing the loss of life and material damage associated with natural hazards from volcanic eruptions.

Conclusion and Recommendations

Analysis of the characteristics of active volcanoes on the continent from fairly recent scientific studies shows a concentration within the EARS and the CVL in Central

Africa. It also indicates that considerable progress has been made in understanding the hazards associated with the various materials produced during eruptions. By contrast, the processes that occur inside a volcano prior to an eruption are less well understood even for the well-studied volcanoes and almost all the volcanic eruptions are preceded by periods of unrest, which include earthquakes, emissions of gases, changes in temperatures, and changes in the chemistry of hot springs and fumaroles as magma rises to the Earth's surface. The hazard level of many volcanoes is still highly uncertain.

It is accordingly recommended that active volcanoes be prioritised for geological studies (physical volcanology, geochronology, petrology and geochemistry) that document recent volcanic history within a hazard assessment context. Such studies would greatly enhance assessment of potential hazards in the event of an eruption. Furthermore, high risk volcanoes should be monitored by a combination of complementary multi-parameter techniques, including volcano-seismic networks, ground deformation, temperature, gas emissions, and readily-accessible remotely-sensed data.¹²² The technology for most of these techniques is yet to be installed around active volcanoes on the African continent. In fact, most studies on these active volcanoes have been conducted by scientists from other continents through remote-sensing techniques or through periodic trips to affected areas.

From the foregoing analysis, it appears that there is an urgent need for: investment in hazard assessment and monitoring in order to characterise and address volcanic risks; constant monitoring using the more modern and successful approaches of eruption detection; monitoring through satellite observation of SO₂ emissions; and monitoring of the thermal IR manifestation of lava effusion of these volcanoes. This could greatly reduce the vulnerability of populations to these hazards, especially if local scientists, policy makers and the local communities work in synergy towards disaster risk reduction from these active volcanoes.

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CHAPTER 4

Volcanic Terrain in Africa that releases Asphyxiating Carbon Dioxide

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Introduction

Carbon dioxide (CO₂) is one of the major magmatic gases released during volcanic activity. Other minor gaseous phases that commonly associate with it include sulphurous gases, halogens and water vapour. The salient physical properties of CO₂ are that it is colourless, odourless and 1.5 times denser than air; thus, it can accumulate in low-lying places and depressions when released into the atmosphere, without being detected. It is equally highly soluble in water. When CO₂ is released at the bottom of a deep, quiet lake, high concentrations can build up. The solubility of CO₂ increases with hydrostatic pressure. The bottom of deep crater lakes are accordingly suitable environments for the build-up of concentrations of CO₂ gas, which kills by asphyxiation when its proportion and concentration in the atmosphere reach 15 per cent and >350 ppm respectively.

Volcanic systems that have posed CO₂-related hazards and disasters in Africa are presented in Figure 4.1. About 42 crater lakes are present along the Cameroon Volcanic Line (CVL) and some of them (such as Lakes Nyos and Monoun (Figure 4.1)) have released disastrous levels of CO₂ in the past three decades.^{1,2,3,4} Other lakes along the CVL include: Barombi Koto, Barombi Mbo, Mbwandong, Debundscha, Wum, Oku and Manengouba. Lakes Mbwandong and Debundscha are found on the southwest flank of Mount Cameroon.^{5,6}

Outgassing of Lakes Nyos and Monoun

The mantle and paleo-lacustrine environments are pristine sources of CO₂. CO₂ is generated through the mechanism of passive degassing.^{7,8,9} After degassing, ground-water conveys the gas to and accumulates it at the bottom of lakes,¹⁰ which are physically and chemically stratified, thereby changing the colour of the lake water (Figure 4.2a). In 1984 and 1986, rock falls triggered the overturn of lakes Monoun and Nyos, respectively, causing a sudden release of CO₂-enriched gas that flowed

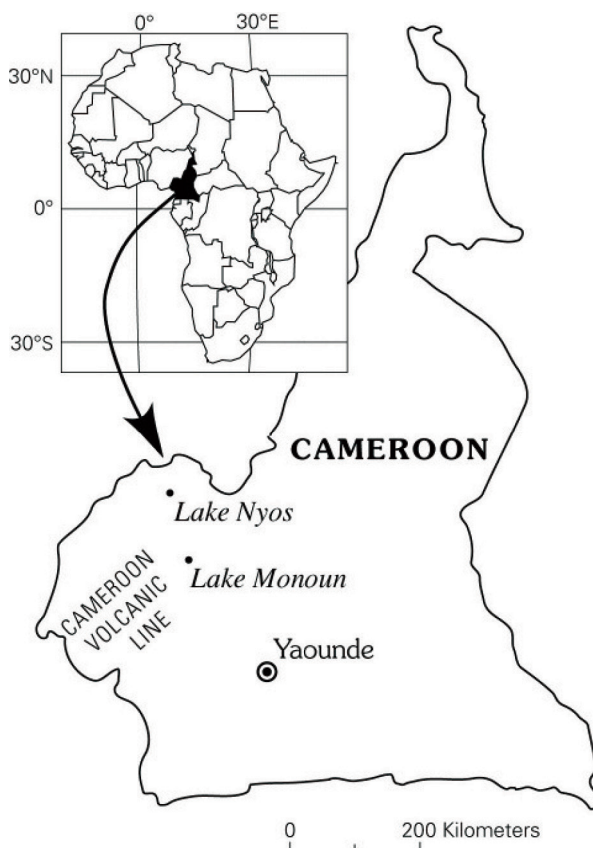


Figure 4.1: Map of Cameroon, showing position of Lake Nyos and Lake Monoun, both found along the Cameroon Volcanic Line.¹¹

along valleys and killed about 1 800 people and 3 000 cattle (Figure 4.2b).^{12,13} Other studies carried out at lakes Nyos and Monoun¹⁴ support the findings that exogenous disturbance or intrinsic instability may upset the density stratification of the lakes' water columns, thus: triggering an overturn of the lakes; and subsequently releasing suffocating CO₂ gas into the atmosphere.

The events that took place at lakes Nyos and Monoun have been described as odd and as tragic episodes that went almost unnoticed. The event in which Lake Monoun outgassed was the first time in history that a lake had degassed, asphyxiating human beings and animals with developed characteristics (e.g. cattle) on such a scale in a single and brief non-direct volcanic event.¹⁵ In the years that followed this gas outburst and the outburst at Lake Nyos two years later, thorough investigation into the physics and chemistry of lakes Monoun and Nyos progressively revealed that both still contained huge amounts of dissolved CO₂.^{16,17}

Since it is impossible to guarantee perennial stability of the lakes and indefinite containment of their very particular 'weapon of mass destruction,' a degassing



a)



b)

Figure 4.2: Photograph of the Lake Nyos disaster showing: a) change in colour of water in Lake Nyos after CO₂ explosion (inset shows lake colour before explosion); b) livestock killed by CO₂ explosion in Lake Nyos.

process was initiated at lakes Nyos and Monoun in 2001, with the CO₂ stored in them being extracted in a controlled manner, to make these lakes safer for the populations living around them. Early warning alerts were also placed in the vicinity of these lakes.

Today, the origin, mechanism and effect of lake degassing are understood to be a new type of natural disaster. This type of disaster is referred to as a 'limnic eruption', a term first coined by J-C Sabroux (at a UNESCO conference on the Lake Nyos disaster that was held in March 1987, in Yaounde, Cameroon) to describe this violent overturn.¹⁸ This term encompasses the sequence of events and consequences of the Monoun and Nyos disasters.¹⁹

Recent advances in studies on limnic eruptions have identified volcanic systems in sub-Saharan African countries (e.g. Tanzania – Lake Tanganyika; Democratic Republic of Congo (DRC) – Lake Kivu) other than Cameroon (with lakes Nyos and Monoun) as being at risk of such a disaster (Figure 4.3). The risk arises when CO₂-rich gases are generated from the mantle, accumulate as gas pockets²⁰ and leak into lakes or discharge at the surface as soda springs.²¹

This phenomenon is now much better understood. Studies carried out at these lakes identify the CO₂ source as magmatic in origin.²² The absence of significant amounts of hydrogen sulphide and halogens, which are typical of high-temperature volcanic gas emissions, suggests that direct injection of volcanic gases into these lakes is not the source of the CO₂. The CO₂ is apparently derived from slow degassing of magma at depth and it then diffuses along fracture zones into the bottom of the lakes.²³ With the release of magmatic gases, any exogenous disturbance or intrinsic instability may upset the density stratification of the lake water columns since CO₂-laden water is denser than pure water. This would then trigger an overturn of the lake, and subsequently release suffocating CO₂ gas into the atmosphere.²⁴

Previously observed limnic eruptions at lakes Nyos and Monoun and future threats from other lakes such as Lake Kivu in the DRC (reportedly characterised by significant quantities of CO₂ and methane) highlight the need for more systematic physical and geochemical studies of all lakes along the CVL and at Lake Kivu.

These lakes are surrounded by granitic and pyroclastic deposits. Lake Nyos in Cameroon, for example, is bound to the east and south by granitic rocks and to the west by an intercalation of basalt and pyroclasts. To the north is the main outlet, which is a natural 45 m-thick pyroclastic dam. It has been reported that this natural dam is prone to physical and chemical weathering that could result in its collapse, which would lead to floods that would pose a devastating threat to inhabited areas in both Cameroon and neighbouring Nigeria.^{25,26}

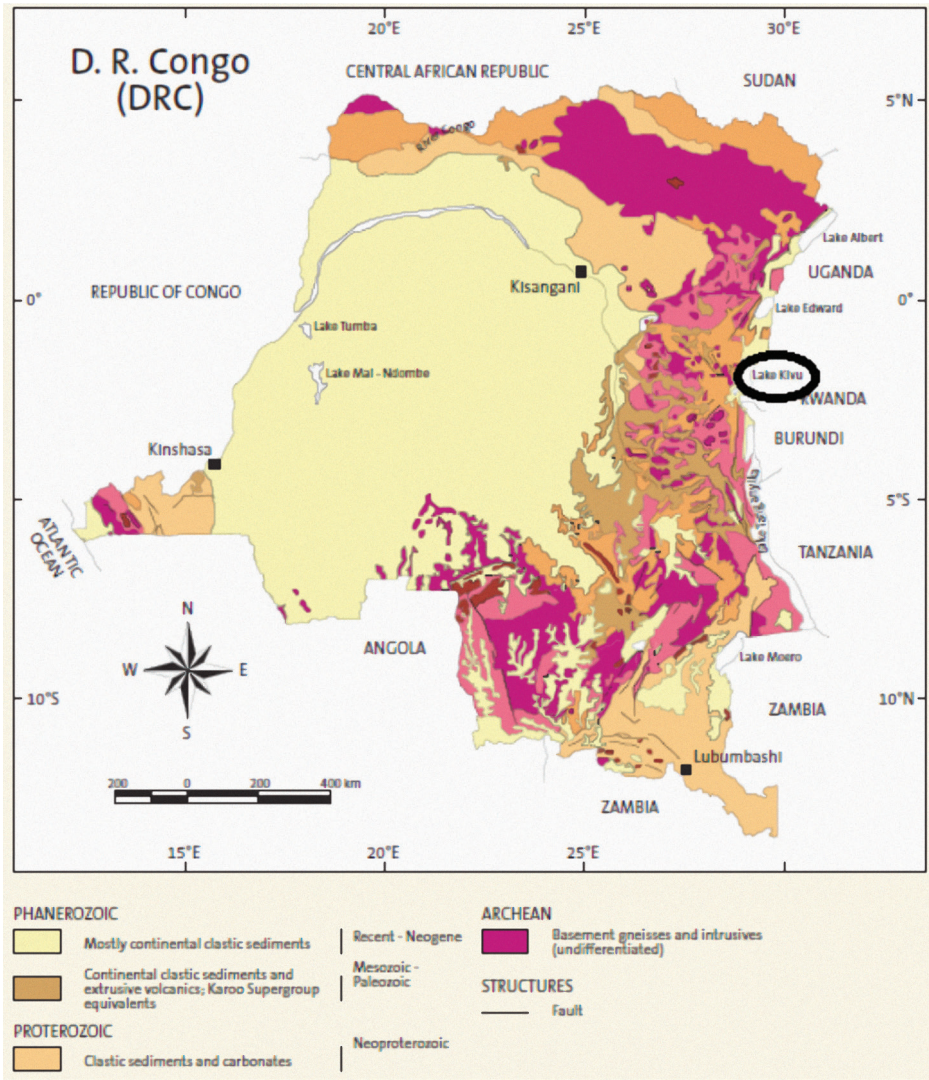


Figure 4.3: Geological overview of DR Congo showing Lake Kivu and other lakes.²⁷

Hazards and mitigation strategies related to lakes Nyos and Monoun in Cameroon

As mentioned above, Lake Monoun was the site of a catastrophic gas explosion in 1984, which killed 37 people. Two years later, in August 1986, Lake Nyos exploded, releasing about 3 million m³ of CO₂ killing over 1750 people. Lake-monitoring studies²⁸ showed that: the killer gas in both lakes was magmatic CO₂ and that gas concentrations in both were increasing, thus increasing the potential for another gas explosion. To prevent similar catastrophes, the government of Cameroon created the Nyos-Monoun Degassing Project (NMDP). This project is run by an international

scientific committee that monitors the degassing of these lakes and other hazards (e.g. flooding and landslides) in their vicinity. The objectives of the NMDP are to: (1) install a continuously operating CO₂ monitoring system near populated areas close to each lake; and (2) to install pipes in the lakes that will safely siphon gas-rich bottom water to the surface, thus liberating the CO₂ from the bottom and into the atmosphere.

Carbon dioxide early warning systems were installed at both lakes. These stations contain infrared CO₂ detectors that continuously monitor CO₂ concentrations in the atmosphere. The atmosphere normally contains about 0.03 per cent of CO₂ but, when this reaches five per cent, it will extinguish a flame and is dangerous to both animals and people. The warning system sounds a siren when the CO₂ concentration in the atmosphere reaches five per cent (about 10 times higher than the normal value). The siren sounds continuously until the gas concentration drops below a dangerous level.

Three artificial degassing systems installed at Lake Monoun after 2003 have removed almost all the gas from the lake, so it is presently believed to be void of accumulated gas,²⁹ but the question remains whether the gas can build up again after the artificial degassing stops. Thus, continuous monitoring of the lake's chemistry will be necessary. At Lake Nyos, about 32 per cent of the gas it contained has been removed by three degassing pipes that were installed in 2001, 2010 and 2011. The year 2014 marked the period when Lake Nyos was expected to be void of accumulated gas. Results from these are still pending.

As mentioned above, the northern border of Lake Nyos is confined by a 40 m-high natural dam made of unconsolidated pyroclastic deposits.³⁰ Lockwood and others in 1988³¹ conducted carbon-14 (¹⁴C) radiometric dating on a piece of wood collected from the base of the dam. This produced an age of 400 years BP. This age is assumed to be the formation age of the Nyos maar.³² Since the original width of the pyroclastic cone is estimated to have been several hundred metres wide, the back erosion rate may be as high as 1.5 m/y, considering the actual width of the dam (45 m). Further calculations suggest that, if the dam were to fail due to back erosion, a devastating flood could occur that would sweep areas along the valley of the River Katsina-Ala as far as Nigeria and affect over 10 000 people.^{33,34}

A different radiometric dating method that made use of potassium-argon (K-Ar) obtained from basalts collected from the dam produced an age range of 110 to 450 Ka.³⁵ To solve the problem of inconsistencies in estimates of the age of the dam, which has implications for the evaluation of the flood hazard, Aka and others in 2008³⁶ applied the U-Th-Ra disequilibrium technique. This technique showed that Lake Nyos is older than 5 Ka, but younger than 8 Ka. This led to the conclusion that the stability of the dam is a cause for concern but that, in the absence of an external trigger, the collapse of the dam from erosion alone is not imminent. At the moment, work is being conducted by a European-funded project to reinforce the dam.

Carbon dioxide (*mazukus*) hazards related to Nyiragongo and Nyamulagira volcanoes

Another peculiar hazard associated with Mounts Nyiragongo and Nyamulagira in the DRC are the *mazukus*.³⁷ This word means 'evil wind' in Swahili. It corresponds to depressions where CO₂ accumulates in high concentrations and at a lethal level. Fifteen per cent of CO₂ is considered a deadly level in the atmosphere; exposures to levels above this are considered intolerable. *Mazukus* are abundant in the city of Goma (situated in the southward flanks of these volcanoes) and its environs and more generally south of the Nyiragongo and Nyamulagira volcanoes.³⁸ From field observations, it was determined that the source of these *mazukus* could be either:

1) a link between the CO₂ source and a network of fractures that allows the gas to reach the surface or 2) a depression, where gas can accumulate by gravity with the source of the CO₂ tied to the mantle.³⁹

Even though there has been an awareness of *mazukus* for a long time, their mode of formation has never been studied and it is still a subject for debate. According to the locals in this area, people are killed by these gases every year. On the basis of the current demographic and urban growth in Goma, which has led to the encroachment of people on hazardous areas, the risks associated with *mazukus* have increased accordingly.

So far, information and prevention campaigns have been carried out in this region to sensitise the population to *mazukus*. Signposts (billboards) have also been installed in some of the depressions, alerting the population to the danger associated with them. However, more work is required, based on the rapid population growth in this area. From a long-term perspective, it is recommended that a systematic mapping exercise be carried out in the area to constrain and test the already existing hypotheses on the formation of *mazukus*. Furthermore, proper urban management is necessary in this volcanic-risk area.

CO₂ outgassing from Lake Kivu in Virunga Volcanic Province

The only other lake known to contain gas-rich bottom water is Lake Kivu (in the DRC) in east Central Africa, where plans for piping are being developed.⁴⁰ Lake Kivu is one of the largest East African Rift lakes, with a surface area of 2 400 km² and a maximum depth of 485 m (Figure 4.3).^{41,42} The deep water of Lake Kivu contains enormous amounts of dissolved CO₂ (250 km³ Standard Temperature and Pressure (STP)) and methane (60 km³ STP). The release of only a fraction of these gases could have catastrophic consequences for the densely populated region. Presently, the gas concentrations in Lake Kivu are below 60 per cent saturation, which would require an extraordinary event to trigger a gas eruption.⁴³

Recent measurements of methane concentration in this lake showed an increase of 15 to 20 per cent during the last 30 years. This has decreased the heat input

needed for triggering a devastating gas release by magma intrusion. With the estimated recent methane production, the gas concentrations could approach a critical level during this century.⁴⁴

Conclusion

The release of asphyxiating CO₂ gas from volcanic terrain in sub-Saharan Africa has been shown to be concentrated along the CVL, where, in 1984 and 1986, outgassing from lakes Monoun and Nyos (respectively) killed about 1 800 people. Although the events were described as odd, since such a disaster had never been observed before, CO₂ outgassing has since been observed in other volcanic terrain on the continent: around Mounts Nyiragongo and Nyamulagira in the Virunga Volcanic Province in the DRC (where the deadly CO₂ is referred to as *mazukus*); in Lake Kivu, within the same volcanic province; and in Lake Tanganyika in Tanzania. Although people have known about the *mazukus* for a long time, the *mazuku* mode of formation has never been studied and *mazukus* are still a subject for debate, even though the locals in the area attest to the fact that people are killed by these pockets of gases every year.

Ongoing steps to mitigate further disasters from the gas within the affected areas include degassing lakes such as lakes Monoun and Nyos in Cameroon, where the concentration of gas at the lake bottoms has been reduced. It is, however, not known whether the gas will build up again if the degassing process is stopped. The mode of formation and occurrence of the *mazukus* in DRC is also uncertain and the high concentration of gas in Lake Kivu would pose a threat to communities within its vicinity if it were triggered to outgas by lava flowing into the lake from the neighbouring active volcano of Mount Nyiragongo.

Further research and, in particular, an assessment of the risks and vulnerability of the communities in these volcanic regions are essential for ensuring the socio-economic development of the regions, owing to the fatalities and health hazards associated with these gases.

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CHAPTER 5

Mass Movements in Sub-Saharan Africa

Kifle Woldearegay

Introduction

Mass movements are among the common geohazards that cause major economic, social and environmental problems in both developed and developing countries. The terms 'mass movement', 'landslide' and 'slope failure' are used synonymously in this chapter. Landslide is defined as the down-slope movement of soil and rock under the influence of gravity, without the primary assistance of a fluid transporting agent.¹ Slope failure is assumed to occur when the strength of the slope mass is somewhat exceeded by the stresses within it.

In many countries, economic loss and casualties due to slope failures are greater than commonly recognised.² The high number of landslides makes the total economic loss from such problems (direct damage to agricultural land and infrastructure and indirect damage to economic activity) higher than from other hazardous natural phenomena.³

Slope failures are fairly successfully predictable hazards. If these hazards are predicted sufficiently in advance of their occurrence, economic losses associated with these hazards can be reduced significantly.⁴ Especially in recent years, advances have been made not only in the understanding of the mechanisms of slope failures but also in techniques for slope instability hazard assessment, prediction and mitigation. In spite of such advancements, landslides continue to occur in both developed and developing countries, with higher casualties in developing nations, but with higher economic loss in the industrialised world.⁵ Landslide activities are expected to continue world-wide in the twenty-first Century for the following reasons:⁶ (a) increased urbanisation and development in landslide-prone areas; (b) continued deforestation of landslide-prone areas; and (c) increased precipitation caused by changing climatic conditions.⁷

The variable topographical, geological, hydrological (surface and groundwater) and land-use conditions mean that many sub-Saharan African (SSA) countries (especially in western, eastern, central and southern Africa) are frequently affected by rainfall-triggered slope failures. Little is reported on landslides triggered by earthquakes, except for landslides that have occurred in Kenya.

This chapter assesses the characteristics, causes and failure mechanisms of mass movements in SSA and suggests strategies that could be adopted to mitigate such hazards on the continent.

Regions in Sub-Saharan Africa at Risk from Landslides

Although no comprehensive inventory of landslides and landslide-generated ground failure has been produced to date, various researchers have reported on landslides in different countries in SSA. Some of these reported landslide incidents are summarised below.

Landslides in Ethiopia: Rainfall-induced landslide hazards have been causing loss of life⁸ and damage to agricultural land⁹ in many areas of the highlands of Ethiopia. Steep slopes, 'squeezed' concave segments, highly jointed and weathered rocks, and the action of both rivers and humans have created an environment that is conducive for triggering slope movements in many parts of Ethiopia.¹⁰ The causes of landslides in the northern highlands of Ethiopia include topographic variables, lithological factors, land use/land cover, and natural and artificial excavation.¹¹

Landslides in Cameroon: Landslides remain the major geohazard and not only cause loss of life but also bring major economic loss to Cameroon.¹²

Landslides in Kenya: Over the last decades landslides have caused major loss of life, livelihood and property, and thousands of people are affected by these hazards in Kenya.¹³

Landslides in Uganda: Mass movements have been among the major hazards in Uganda and result in loss of life and economic costs.¹⁴

Landslides in Malawi: Landslides are common in different parts of the Malawi, and some of fatal mass movements (primarily debris flow) in the country include: (a) the 1946 Zomba Mountain landslide, which claimed 21 lives and caused damage to property and infrastructure; and (b) the Phalombe landslide of 1991, which claimed over 500 lives and caused extensive damage to crops, bridges and buildings.¹⁵

Landslides in Rwanda, Tanzania and Democratic Republic of Congo (DRC): Landslides in Rwanda have been among the main geohazards faced by the country.¹⁶ Such hazards are also common in Tanzania.¹⁷ In the DRC, landslides have caused major problems in different parts of the country.¹⁸

Landslides in Nigeria: This country is one African region that has been affected by extensive gully erosion and associated landslides. Landslides in Nigeria are associated with gully erosion, rock type, hydrogeological factors and anthropogenic variables.¹⁹

Landslides in South Africa: Landslides of different types (debris or earth slides, debris flow and rockfalls) are reported to have occurred in South Africa. Slope angle, lithology and climatic variables are considered to have contributed to slope instability in South Africa.²⁰

Classification of Mass Movement Processes

Types of mass movements range from the creep of slow movements (less than 0.15 mm per year) to instantaneous and catastrophic slides (1.5 m per second).²¹ The major types of slope failures in SSA countries include: creep, slide, fall or topple, flow and spread. Each of the different slope failure types could have a number of common modes.²² Falling and toppling are features frequently associated with rock slopes; flowing and spreading are related to soil slopes; and creep and slide are related to both soil and rock slopes.²³

Although rockfalls are not uncommon in many parts of SSA, most reported rainfall-induced landslides include: debris or earth flow (Figure 5.1),²⁴ debris or earth slide and rockslides. In relation to size, the failed masses have varied from small debris or earth slides to large-scale slides (e.g. 5 km wide * 8 km long mass movement in Ethiopia) (Figure 5.2), with failure mechanisms that range from small translational slides to complex quasi-rotational rockslides.



Figure 5.1: Landslide at Nametsi Village, Uganda, where over 300 people, homes and a community health centre were buried by the debris flow.²⁵



Figure 5.2: Partial view of the 2006 landslide in the Tarmaber area, Ethiopia. Over 3 000 people were displaced as a result of the large-scale landslide (areal size: 5 km * 8 km).

Controls and Triggering Factors of Mass Movements

Evaluation of the relationship between slope failures and various factors have revealed that most rainfall-triggered landslides in SSA have similar characteristics: mass movements prevail in areas with certain bedrock types, slope gradients, slope shapes, vegetation cover, gully erosion and slope modification due to road excavations.

Influence of bedrock type on mass movements

Factors related to the nature of the materials and discontinuities in rock may have an influence on the engineering characteristics of slope masses, as they cause variation in the permeability, strength and deformation characteristics of soil and rock masses.²⁶

A review of previous studies, as mentioned in the preceding sections of this paper, shows that most of the reported landslides in eastern, western, central and southern Africa have taken place in areas with underlying rocks that are characterised by: (a) low shear strength behaviour; (b) low permeability, which enhances the development of seepage force in the overlying slope masses; and (c) high susceptibility to weathering, erosion and lubrication (softening). This is similar to what was reported in

the case of landslides in Kenya, Uganda, Ethiopia and Cameroon: landslides were recorded in areas with underlying volcanic ash and pyroclastic deposits. Landslides were also reported in Nigeria and Ethiopia in areas with underlying shale or loosely consolidated sediment.

The prevalence of landslides in areas with underlying basalt flows in the highlands of Ethiopia is attributed to the:²⁷

- (a) mode of formation of these rocks, which resulted in horizontal layers of variable hydraulic conductivity that promote lateral flow of water towards the slope surface;
- (b) presence of volcanic ash and lacustrine deposits of low permeability as interbeds within the basalt flows, which enhances lateral flow of water parallel to the slope face; and
- (c) presence of fine-grain-dominated soil at the lower section of the hillslope, which retards drainage and hence contributes to water pressure build-up within the slope because of low permeability.²⁸

In the case of landslides reported in Malawi, failure was recorded in areas with underlying basement rocks. Landslides in these areas are reported to be associated with liquefaction of the unconsolidated deposits that overlie the basement rocks.

Influence of slope gradient on mass movements

Slope gradient has an effect on the prevalence of landslides. Landslides occur in slope gradients in the range 15–50 degrees, with the majority of failures being found in the range 25–40 degrees. The prevalence of slides (debris or earth) and flows (debris or earth) in moderately steep terrain is attributed to the presence of adequate thickness of unconsolidated deposits and higher slope gradients, which generate stresses that could cause failures. No major debris or earth slides and debris or earth flows have been recorded in areas with slope gradients of less than about 10 degrees. This may be because the slope masses have enough strength to sustain any stress that develops on such slope inclinations. On the other hand, absence of major debris or earth slides and debris or earth flows on terrain with slope gradients of greater than about 50 degrees is related to the insignificant thickness or the absence of unconsolidated deposits. Most steep slopes are dominated by slightly- to moderately weathered rocks.²⁹

Influence of slope shape on mass movements

Plan curvature influences the susceptibility of a slope to landslides by governing the distribution of water (surface or sub-surface) within a slope.³⁰ Positive plan curvature values (convex) indicate divergence and negative plan curvature values (concave) indicate concentration of flow. Concave plan terrain promotes concentrated flow of water while convex plan terrain causes divergence of flow.³¹

Although no systematic comparison of slope shape and landslides has been made for all the reported landslides in SSA, many of the landslides have taken place on concave areas where there is thick soil cover. The high susceptibility of concave areas to rainfall-triggered landslides is the result of such terrain being associated with: (a) convergent water flow (surface and sub-surface), which leads to water pressure build-up; (b) high susceptibility to sub-surface erosion (piping) due to concentrated sub-surface water flow along pervious layers; and (c) greater thickness of unconsolidated deposits, since such areas are generally zones of material accumulation, as mentioned by several authors.³² Landslides are absent in convex plan terrain because this terrain tends to disperse surface and sub-surface water flow and is associated with material depletion through erosion.

The observed higher frequency of slope failure in the concave terrain of the northern highlands of Ethiopia correlates with what has been reported by different authors indicated in the previous sessions of this chapter. In the Ethiopian highlands, concave terrain is often susceptible to rainfall-triggered slope failure as such terrain is characterised by high moisture concentration and a deeper soil profile.

Influence of slope modification on mass movements

It is well understood that changes in slope geometry (through natural or man-made processes) could influence mass movements. The factors that cause slope modification are:

- (a) Removal of lateral support by erosion (by streams and rivers, glaciers, the action of waves or marine currents, successive wetting and drying), natural slope movement (slides and settlements), and human activity (cuts and excavations, removal of retaining walls, and draw-down of bodies of water);
- (b) Removal of underlying support materials by rivers or seas, weathering, underground erosion from seepage (piping), dissolution of soluble agents, human activity (excavation or mining), and loss of strength of the underlying materials due to various processes, such as weathering; and
- (c) Human activities such as construction of fill, buildings and other overloads at the crest of slopes.

Most of the reported rainfall-triggered landslides in SSA have occurred in areas adjacent to streams or topographic breaks or in places with active gully erosion development. Mass movements have also been recorded along road cuts. The strong relationship of slides and flows with active stream or river incisions and gullying implies that landslides are associated with the stream and river dynamics and land degradation that affect the continent. A typical example of this process is mass movements in Nigeria (Figure 5.3).



Figure 5.3: Mass movement affecting express highway in Onitsha City, Nigeria, which is associated with gully erosion development.

Influence of vegetation cover on mass movements

The role of vegetation in slope stability is a subject of debate; some argue for its negative effect and others for its positive contribution in stabilising slopes. Vegetation influences slope stability by affecting the hydrology or mechanical properties of soil slope masses.³³ Vegetation cover with deeper and wider roots has a positive influence on shallow debris or earth slides, by improving the strength of soil through reinforcement of root networks and buttressing slope masses (by roots anchoring into the underlying bedrock).³⁴

Various authors have reported that deforestation of slopes has been followed by severe shallow landsliding in areas such as New Zealand, Alaska, British Columbia, the Himalayan foothills and Japan. A review of previous studies shows that deforestation has the following disadvantages:³⁵

- Immediate cessation of the stabilising effects of forests, as a whole, on climatic variations, with negative effects on the behaviour of soil facing new stresses. This results in enhanced soil erosion and changes to the micro-climate of the deforested areas, which, in turn, affect the water cycle and expose the soil or rock masses to more interaction with atmospheric processes (which facilitates surface-weathering processes);
- Immediate cessation of interception, retention and evapotranspiration, which then causes an increase in the amount of water that reaches the ground and infiltrating water;

- The loss within a short time of the effects of the superficial debris layer for retention and slow-down of runoff, with a consequent increase in erosion and infiltration;
- A rise in the groundwater table, as a consequence of elimination of evapotranspiration, with possible effects on saturation of the superficial soil, and an increase in weight; and
- Loss, within a certain time, of the mechanical effects of the root systems, eventually reducing the induced apparent cohesion and, consequently, the shear strength of the natural slope mass.

Most reported landslides in SSA have occurred in places with scarce or no vegetation cover.

In relation to mass movements that involve deep-seated failure, vegetation cover is believed to have little effect in controlling this failure. However, vegetation cover could play a positive role in slope stability, by influencing hillslope hydrological processes, even for failure surfaces deeper than the general depth of root penetration.³⁶

Effect of Landslides and Linkages with other Natural Hazards

Mass movements in SSA mention that such hazards have been causing economic, social and environmental problems. To mention Ethiopia, as a case, a summary of the reported mass movements includes the following problems:

- From 1993 to 1998, landslides or landslide-generated problems claimed about 300 lives, damaged over 100 km of asphalt road, demolished more than 200 dwelling places and devastated in excess of 500 ha of land in Ethiopia.³⁷
- In the years 1998 to 2003, 135 human lives were lost, about 3500 people were displaced and an estimated US\$1.5 million worth of property was damaged in the highlands of Ethiopia.³⁸
- Landslides in Dessie have affected roads, buildings, pipelines and other infrastructure in the town.³⁹
- As a result of a single large-scale landslide in the Tarmaber area: more than 3 000 people were displaced; 1 250 dwelling places were demolished; 4 churches, 4 mills and an elementary school were destroyed; and over 1 500 ha of farm land were destroyed.⁴⁰
- The spread of malaria in different parts of Ethiopia is affected by landslides through the creation of surface water ponds (especially in low-altitude areas)⁴¹
- Sedimentation or siltation of reservoirs is aggravated by landslides in the watershed of several micro-dams in Tigray, northern Ethiopia.⁴²

Mass movements affect infrastructure (Figure 5.4)⁴³ and agricultural land (Figure 5.5) in different parts of SSA.



Figure 5.4: View of a rotational landslide at Kie Village developed on weathered pyroclastic cone characterised by reddish to reddish-brown soils. The green structure at the centre-left edge of the picture is a 300 m³ water tank, which is partially buried by slide debris.⁴⁴

Rainfall-induced mass movement hazards in SSA are closely linked with hydro-meteorological hazards such as flooding and erosion (Figure 5.5). This is shown by the strong association of landslides with stream or river incision and with gully erosion.



Figure 5.5: Typical example of effect of stream or river incision on landslide in Adishu area, northern Ethiopia, which is affecting agricultural fields.

Mechanisms that Trigger Landslides

Various authors have indicated a relationship between rainfall and landslides. Both antecedent rainfall and critical intensity of rainfall are important factors in triggering landslides.⁴⁵

Most of the reported rainfall-induced mass movements in countries in the sub-Saharan region have taken place during periods of prolonged and heavy rainfall, and have occurred at the end of the rainy season. The majority of mass movements in this region are, therefore, believed to have occurred as a result of a combination of: (a) shear strength reduction, due to saturation in the upper part of the soil profile; and (b) build-up of positive pore water pressure in the lower parts of the slope profile.⁴⁶ Establishing a relationship between landslide events and rainfall has important implications for landslide monitoring and forecasting in the region.⁴⁷

Predicting and Minimising Landslide Hazards

In order to reduce losses from landslides and associated geohazards it is necessary to predict landslide hazards and design strategies to mitigate them. Increased pressure on land in many sub-Saharan countries has meant that rural people have moved into areas that are potentially threatened by slope instability hazards. Currently, many towns and cities are expanding into landslide-prone areas, without any prior slope instability hazard assessment and risk analysis. SSA countries are becoming growth centres and massive infrastructure development is taking place in these countries. Landslides pose serious challenges to infrastructure development on the continent, as many of the roads and railroads have to cross areas that are endangered by first-time failures or reactivated old landslides. This is complicated by the increase in land degradation processes (deforestation and erosion), coupled with climate change.

Mass movement hazards are becoming a major concern to the public and to decision makers and planners at various levels. In spite of this, however, so far, little effort has been made to reduce losses from such hazards. Major landslide-related issues include the following:

- The causes and mechanisms of slope failure of large-scale landslides remain poorly understood;
- Many of the landslides remain unreported and no comprehensive assessment of the losses caused by such hazards has been made so far. Landslide records, if they exist, remain stored in different places and formats and on different scales;
- The continent lacks not only a responsible institution that could play a leading role in landslide hazard assessment and mitigation but also feasible policies for landslide risk management;
- The planners and decision makers, who are mostly involved in emergency issues such as evacuation and resettlement of people displaced by landslide hazards,

have limited awareness of the magnitude, frequency and socio-economic impact of such problems;

- Public awareness of landslide hazards is low and these hazards are perceived as acts of God by many rural communities;
- The continent lacks skilled manpower and professionals who could be involved in landslide assessment, prediction and mitigation; and
- Landslide-related research, and information management and dissemination are poor.

With the current trend in population expansion, increase in urbanisation/ development, poor ecosystem management, and high rainfall variability (due to climate change) on the continent, it is likely that the scale (frequency and magnitude) of mass movements and the costs related to such hazards will continue to increase. Mitigation will require that: (a) processes leading to the triggering of a landslide are properly understood; (b) landslide-susceptible terrains are properly mapped for development planning; and (c) appropriate mitigation strategies are designed and implemented.

The mitigation strategies suggested here are aimed at:

- Saving lives and reducing public exposure to landslide risk;
- Reducing damage to private and public property and infrastructure;
- Minimising the effects of landslides on natural resources and the natural environment;
- Improving public and decision-maker awareness of landslide hazards and the management of such hazards; and
- Improving the technical skill of professionals involved in landslide risk management.

The following landslide-hazard mitigation strategies, believed to be feasible for application in SSA, are recommended:

- (1) Establish an institution that could play a leading role in research, trainings/ capacity building, and policy support activities on landslides;
- (2) Develop policies and guidelines on landslide risk management;
- (3) Initiate and promote capacity-building programmes;
- (4) Initiate and promote collaborative landslide hazard mapping, loss assessment and research;
- (5) Initiate and promote landslide hazard forecasting and monitoring; and
- (6) Adopt feasible and multi-purpose remedial measures.

Establishing responsible institutions at country level or regional level

In many of the countries in SSA, the economic and environmental costs from mass movement hazards have not generally been recognised as a problem of national

importance. This is mainly because: individual landslides usually affect a limited local area and individual landowners; and no comprehensive inventory of losses from such hazards has been made that would justify their economic, social and environmental significance.⁴⁸ State leadership would play a key role in addressing landslides. Reliable and mandated institutions should be established at country or regional levels, which could play a central and leading role, not only in landslide risk management but also in landslide-related information management (collection and storage) and in dissemination of information to users.

Developing policies and guidelines for landslide risk management

To implement mass movement mitigation strategies, proper policies, legislation and guidelines are needed that relate to, among others: (a) building codes on excavation, construction and grading; and (b) land-use regulations and the management of landslide-prone areas.

Initiating and promoting capacity-building programmes

Knowledge and awareness of the causes, mechanisms and effects of landslides is the basis for mitigating and predicting slope hazards. It is therefore important to initiate and promote capacity-building programmes that involve training:

- (a) Local people and local level government leaders on landslide hazards and their mitigation, in this way creating awareness in society;
- (b) Experts who are involved in landslide hazard management; and
- (c) Decision makers to promote awareness of the significance and causes of slope failure and on landslide hazard management.

Initiating and promoting collaborative landslide hazard mapping, loss assessment and research

Mitigation of mass movements can be effective only when detailed knowledge is available about the expected frequency, character and magnitude of the hazards.⁴⁹ Moreover, landslide hazard mapping and prediction are important for planning and decision making. It is important that landslide hazard mapping, loss assessment and research are conducted in SSA in collaboration with institutions from developed countries that have experience and knowledge of landslide hazard assessment and mitigation. This collaboration in research, hazard mapping and knowledge/information sharing could involve, among others:

- Compiling and evaluating information on the economic impact of landslides;
- Delineating areas that are susceptible to landslide hazards at a scale appropriate for development planning and decision making; and
- Promoting further research on landslide initiation, prediction and remediation.

Initiating and promoting landslide hazard forecasting and monitoring

Forecasting and monitoring of potentially unstable slopes are important for minimising risks from slope failure. In many SSA countries, a simple early warning system could save lives and prevent other forms of human suffering through the establishment of possible relationships between rainfall and landslide events. This type of early warning system is often based on the assumption that a direct relationship exists between the occurrence of landslides and the characteristics of rainfall (such as intensity, duration and antecedent rainfall).⁵⁰ It is highly recommended that nationwide landslide predictions are developed through establishing rainfall-landslide relationships in collaboration with national or international weather service organisations. It is also advisable that monitoring systems of shallow groundwater levels and fluctuations are established. With active landslides that pose a higher risk to communities and infrastructure, it is advisable that ground-monitoring systems on rates and magnitudes of movements be initiated.

Adopting feasible landslide remedial measures

Mitigation of mass movements or prevention of potentially unstable slopes often aim at reducing the driving forces, increasing the available resisting forces, or both.⁵¹ Landslide mitigation measures can be grouped into four approaches: modification of slope geometry, drainage, retaining structures and internal reinforcement.⁵²

Most of the rainfall-triggered landslides in SSA prevail in areas with no vegetation or sparse vegetation cover and in areas adjacent to streams or rivers affected by active stream or river incision and gully erosion. Taking into consideration the processes that lead to instability of a slope, and the social and economic conditions of the country, one or a combination of the following remedial options are recommended: (a) drainage-based water harvesting; (b) promotion of afforestation and reduction of deforestation; (c) reduction of stream and river incision and gully erosion; (d) provision of retaining structures, where necessary; and (e) planning control, where appropriate.

(a) Drainage-based water harvesting

Drainage of water (surface water and groundwater) is the most widely used and generally the most successful slope-stabilisation method because it reduces the destabilising seepage force on a slope and the risk of (piping) erosion of the materials within the slope.⁵³

Drainage-based surface or sub-surface water harvesting is believed to be the best option, as a major landslide hazard remedial measure in many of the SSA. Surface water could be drained, so as to reduce surface water infiltration into landslide-prone areas and then stored in small-scale surface water reservoirs, if required. Sub-surface water could be drained using shallow vertical wells, trenches and horizontal drains – depending on site conditions. The harvested water could be used for various

purposes, including water supply or small-scale irrigation, where appropriate. This approach could improve not only the stability of slopes but also the economic condition of nearby communities.

(b) Promotion of afforestation and reduction of deforestation

For centuries, wood and living plants were the only materials used for hill- and slope-stabilisation works. The observed high prevalence of landslides in areas with sparse or no vegetation cover in many of the SSA countries suggests that type of vegetation influences slope stability. Vegetation, in general, plays a positive role in slope stability. It is therefore advisable to reduce deforestation and encourage afforestation with trees that have deeper and wider roots.

(c) Reduction of stream and river incision and gully erosion

The majority of debris or earth slides and debris or earth flows have been found to be associated with streams and rivers that are affected by gully erosion. This makes it necessary to provide protective blocks (such as gabions filled with stones) and other soil-conservation engineering measures coupled with biological measures to reduce stream and river incision and gully erosion and to enhance deposition of sediment in stream and river channels. This could have a long-term stabilisation effect. This could be undertaken in collaboration with environmental and agricultural agencies in a country and integrated with land management programmes.

(d) Provision of retaining structures

Placing retaining structures at proper locations of a sliding mass generally increases the stability of slopes by increasing resistance to movement. This method could be applied at specific sites, especially in cases where landslides are associated with road cuts or in areas where sensitive engineering structures exist. The most feasible remedial options are to apply masonry or stone retaining structures, coupled with surface or sub-surface water drainage. It should be noted that, depending on the risk to sensitive infrastructure and human safety, other engineering measures such as concrete retaining structures could also be used.

(e) Planning control

Planning control is a commonly used, effective and economical way of reducing landslide loss. It could involve: (a) removing or converting existing development; or (b) discouraging or regulating new development in unstable areas. Planning control is generally recommended in conditions where slope instability cannot be overcome effectively and economically.

On the basis of site-specific hazard evaluation and risk analysis, planning control is one mitigation option that should be considered in many areas of SSA. Landslide-affected areas could be used for different purposes; for example, as open spaces,

woodlands or recreation areas. Maps related to landslide hazards (at various scales) are valuable tools and need to be promoted in SSA countries.

Conclusion

Despite their huge economic, social and environmental significance, so far, mass movements in SSA have not been given due attention. Rainfall-triggered landslides continue to cause loss of life and damage to infrastructure, agricultural lands and the environment. Such hazards are expected to increase on the continent as more people move into unstable terrain and construction expands into fragile terrain, without proper prior site investigation. These problems could be further aggravated by climate change. It is, therefore, necessary to adopt strategies that address landslides on the continent. This landslide issue in SSA call for, among others: (a) the establishment of research centres that could play a key role in landslide management at country or continent level; (b) the development of appropriate mitigation strategies; and (c) the promotion of comprehensive capacity building in mass movement hazard assessment, prediction and mitigation in the continent.

The following recommendations are made for further landslide research in SSA:

- Most of the so far reported landslides on the continent are rainfall-triggered. For mass movement hazard mapping/zoning and predictions, rainfall, soil-water interactions, and groundwater fluctuations need to be monitored and the hydrological process of hillslopes understood. Moreover, landslide-groundwater and landslide-rainfall relationships need to be understood, as this relationship could be used to develop an early warning system for mass movement hazards (at state, regional or continent level).
- The causes and failure mechanisms – and hence factors that contribute to the triggering of mass movements – are not well understood and these would be the base for hazard mapping and prediction. It is therefore recommended that all recent landslides (that have occurred over the years) be mapped.
- The failure mechanisms of the medium- to large-scale rockslides indicated in this chapter were assessed on the basis of the distribution of rock and soil masses and field observations of features that indicate mass movements. In order to improve our understanding of triggering of failure of such large-scale rockslides, further research is recommended. This research should include field monitoring and numerical modelling.⁵⁴
- Much of the mountainous terrain of SSA remains highly fragile in terms of mass movements: any external factors, such as heavy rainfall or excavation, could lead to slope failure. Prior to any development planning, it is advisable to undertake proper landslide hazard assessment and risk analysis in certain areas. In many SSA countries, mass movements have been found to be associated with deforestation and gully erosion. These processes are expected to be aggravated

by climate change, population increase and urbanisation. It is, therefore, necessary to consider landslide mitigation as part of ecosystem management on the continent.

- To improve the capacity of countries in SSA to address mass movements, it is necessary to establish research centres and institutions, create regional networks and undertake training on mass movements on the continent.

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CHAPTER 6

The Impact of Artisanal Gold Mining on the Livelihood of Local Communities in the Macalder Gold Mine Area in Kenya

Beneah D. O. Odhiambo and David Ongo

Introduction

Artisanal mining includes activities as simple as panning for gold in river beds, to as complex as development of underground workings and small-scale processing plants. The last few decades have seen increasing international attention being paid to artisanal small-scale mining (ASM). The beneficial role of ASM in society and its economics in many developing countries are often overlooked, while its negative impacts seem to dominate official press coverage, scholarly meetings and publications. ASM has seen unprecedented growth in developing economies over the past few decades. The International Labor Organization (ILO) estimated that: there were between 11 and 13 million artisanal miners worldwide, almost 30 per cent of whom were women; 80 to 100 million people worldwide are directly or indirectly dependent upon ASM for their livelihoods.¹

Small-scale gold mining is a significant source of mercury being released into the environment, with: as much as 800 tons/yr of metallic mercury being released into the environment worldwide; between 120 to 240 tons of mercury is released into the environment every year in China alone, due to gold amalgamation.² Fine dust from mineral processing causes silicosis in the mining environment and noise pollution are both endemic problems. ASM accidents are often under-reported, due to the illegal or semi-legal status of most ASM operations. Non-fatal accidents in ASM were estimated to be 6–7 times higher than in the formal mining sector.³

In Kenya, most of the mineable gold deposits are found in small quantities, which are often not viable for large-scale mining. ASM has grown to become a significant method of exploitation of such deposits. The mining method employs crude technology to extract gold from the ore and it is undeniably dangerous to the health and safety of the mineworkers, who are not trained in mining and mining operations but have capital to invest in the purchase of appropriate equipment.

Gold mining is a hazardous activity that greatly affects the biogeochemical cycles of both toxic and non-toxic elements. In Kenya, both abandoned gold mines and the ongoing artisanal gold mining operations are a major source of geochemical hazards, which impact negatively on health and safety. However, artisanal mining does make a contribution to the economy, especially in rural areas: it provides employment and contributes to GDP. Thus, infrastructure development should not be overlooked in the planned development of mining areas.

Legal Framework for Mining in Kenya

Any mining project inevitably alters the local physical environment; hence control procedures should be employed to ensure that negative impacts are contained to acceptable levels. All mining operations in Kenya are subject to government regulations, most of which relate to environmental protection and safety in terms of working conditions. The Environmental Management and Coordination Act (Cap. 387) of 1999, is an Act of Parliament that provides for the establishment of an appropriate legal and institutional framework for the management of the environment and for matters connected therewith and incidental thereto. This Act is used together with the Mining Act that is currently being revised.

Mineral exploration and exploitation are currently carried out under the auspices of the Mining Act (Cap.306) of Kenya, and is administered by the Department of Mines and Geology, currently in the Ministry of Mining. The Department is responsible for undertaking geological surveys and geoscientific research, and for coordination and regulation of activities of the mining sector. All un-extracted minerals under or on any land, as per the Mining Act, are vested in the Government, subject to any rights that, under the Act, have been granted to any other person. The licenses outlined below can be granted in terms of the Mining Act.

- **Mining Location Licenses**

These are mostly granted to small-scale miners. The conditions attached to these licenses are more onerous than in the case of other licenses. A location consists of a block of not more than 10 claims. A claim is an area comprising: 20 000 square meters in the case of precious metal i.e. gold, silver, etc., and precious stones (e.g. rubies, emeralds and opals); and 50 000 square meters for all other minerals (e.g. copper, lead, graphite and baryte).

- **Exclusive Prospecting License**

This is granted over an area selected by an applicant who: has a valid prospecting right; has deposited a sum of KES 2 000 (25 US dollars) with the Provincial Commissioner of the Province in the area over which the application made is situated;

has written consent from the relevant local authorities; has written consent from land owners.

- Mining Lease

This is granted for the exploitation of a mineral deposit that has been discovered following successful prospecting and exploration. Table 1 shows mining and prospecting operations in Kenya as at 2010. Mineral exploration, exploitation and trade are presently carried out under the auspices of the Mining Act of 1040 (Cap.306), the Trading in Unwrought Precious Metals Act, 1933 (Cap.309), the Diamond Industry Protection Act of 1949 (Cap.310), and Gold Mines Development Loan Act of 1952.

The law provides that royalties are paid on all minerals mined to both the national and county governments. The rates of royalties are negotiated within the Commonwealth countries' rates; however, these are currently being negotiated. Initially, royalties were only paid for soda ash and carbon dioxide, based on a certain rate per ton of soda ash sold and per kilogram of carbon dioxide produced. Companies with mining leases are currently negotiating their rates.

Revision of the Mining Act (Cap.306) which was enacted in 1940, as well as the accompanying regulations, is long due. The Act is being reviewed in order to promote mineral resource development through national and county governments and the private sector.

Table 6.1: Mining and prospecting operations in Kenya⁴

No. of Companies	Types of minerals mined	District found
11	Base metals (gold, silver, copper minerals, iron ore, lead, chromite)	Transmara, Migori, Homabay, West Pokot, Turkana, Siaya, Kakamega, Vihiga, Kuria, Nandi, Saburu, Kilifi, Kwale, Taita Taveta, Meru
23	Industrial Minerals (Fluospar, Titanium minerals, Diatomite, Vermiculite, Limestone, Gypsum, Silica, Feldspar, Clay minerals, Magnesite, Quartz)	Marakwet, Kwale, Nakuru, Samburu, Kajiado, Machakos, Kilifi, Turkana, West Pokot, Nandi, Tana River, Wajir, Makueni, Taita Taveta, Kiambu, Nyeri, Kisii
112	Gemstones (Ruby, Sapphire, Rhodolite, Tsavorite, Tourmaline, etc)	Taita Taveta, West Pokot, Kwale, Isiolo, Machakos, Kilifi, Mwingi, Turkana, Kajiado, Meru, Samburu, Baringo)
5	Chemical Minerals (Soda Ash, Salt, Carbon Dioxide, Hydrocarbons)	Kiambu, Kajiado, Mombasa, Kilifi, Malindi, Mwingi)
18	Dimension Stone (Granite, Marble, Limestone)	Vihiga, Nandi, Marakwet, Mombasa, Kilifi, Machakos, Kajiado)

Gold Mining in the Macalder Area and Production in Kenya

The promising gold potential in the Macalder gold mining area of Migori County has attracted large mine operators. For instance, the Kansai Mining Corporation completed a drilling programme at Migori in south-western Kenya in the second quarter of 2004. Resources at Migori were estimated to be about 39 metric tons of contained gold. More explorations are still in progress and diamond exploration activities are currently being performed by a Canadian company in Masara.

In 2002, Kansai Mining Corp. of Canada (formerly known as Mid Migori Mining Company Ltd.) engaged in a venture to explore for gold in the Migori County of Nyanza Province. International Gold Exploration AB of Sweden has properties in Nyanza and the Rift Valley Provinces and the company sought also out joint-venture partners for purposes of exploration.⁵

The future of gold mining in Kenya is a subject of great interest and importance to the economy of the country. From what has been learned from past experience, there is little doubt that the large known goldfields of western Kenya offer the most attractive proposition for future development. By world standards, the deepest levels reached at these goldfields is not deep enough to have exhausted the deposit. Naturally, early miners concentrated on extracting the gold lying close to the surface, because this is most easily won at a relatively low cost. Deeper mining involves higher costs and capital resources beyond the reach of most small-scale miners; consequently many small miners are forced out of business when the mining costs approach the profit margin.

Money spent on exploration seldom delivers an immediate return, which means that exploration is usually undertaken by large mining companies that can afford to absorb a loss for a year or more. Alternatively, it could be carried out by Government, as part of a long term policy, with the objective of establishing a new industry or reviving an old one. This latter course is the one that is being followed in Kenya, with the assistance of the United Nations Development Program.

Gold production in Kenya is mainly from artisanal and small-scale mining. National exports of gold amounted to 1,543 kilograms (kg) in 2003, compared with 1 477 kg in 2002 and 388 kg in 1998. In 2004, production dipped, when Muungano Gold Prospecting Group of Kenya and Kansai Mining Corporation began drilling in the second quarter of 2004.

Table 6.2: Gold production in Kenya from 1990 to 2006⁶

Year	1990	1991	1992	1993	1994	1996	1997	1998
Gold Production (kg)	25	20	20	154	154	300	300	388
Year	1999	2000	2001	2002	2003	2004	2005	2006
Gold Production (kg)	990	950	1545	1477	1543	567	616	432

In Kenya, mineral production in 2003 was worth KES 8.2 billion, compared to KES 7.4 billion the previous year. Therefore the country earned more than KES 5 billion from the export of minerals in 2003, compared to KES 4 billion in 2002 – an increase of per cent. Earnings from mineral resources contribute more than one per cent to GDP.

Mining operations have contributed significantly to the economic development of the country, through: the creation of employment opportunities; the creation of a local supply of raw materials for industry; the generation of export revenue; the alleviation of poverty, through the provision of additional alternative livelihood sources; the development of infrastructure and social facilities, such as roads, power supply, schools and health facilities.

Despite the apparently low contribution of the mining sector to world-wide economic activity, the impact of mining on GNP can be high for individual countries, even if it represents a small share of GNP to some countries.⁷

Figure 6.1 shows the quantity of gold and gemstones produced in the period 2000-2003. It can be seen that gemstone contribution was high in 2002, due to improved economy and safety in the country, and a sudden rush of gemstone mining in Kwale and other areas. Ruby production reduced steadily over the three years, while gold production was stable during the three year period.

This shows therefore that gold deposits were not significantly affected over the years by technical and economic factors such as inadequate skills, lack of tools and finances, that hampered the production of gold.

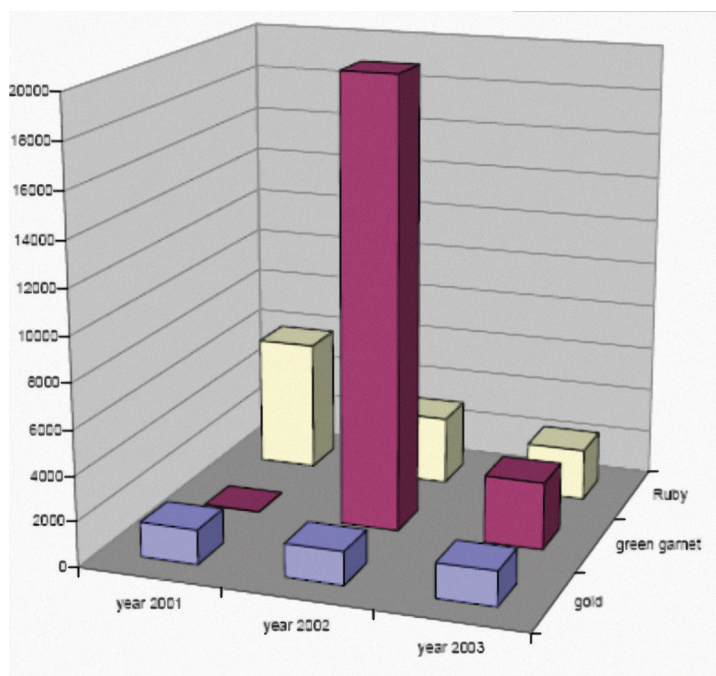


Figure 6.1: Quantity (in kgs) of gold, ruby and green garnet produced in 2000 –2003⁸

Impact of Gold Mining on the Livelihood of Macalder Residents

Mining projects can have a significant impact on the structure of society, the way of life of people, immigration patterns and other social factors, as well as on the physical environment. In some cases, these impacts are more pronounced because of the typically remote location of mining developments, which requires substantial new infrastructure to be put in place. The impacts vary considerably from project to project and from country to country⁹

- Positive Impact

Academics and especially journalists, tend to focus on the negative impact of ASM, and generally under-report its positive aspects. This is certainly the case in China, home of the world's largest ASM industry.¹⁰ While the negative impact should not be under-estimated, overlooking ASM's positive aspects has led to policies that focus on the negative, with little consideration for the wider positive consequences.

The mining industry is often more capital intensive than manufacturing and other industries. The capital labor-ratio and the output labor-ratio depend on the size of the mining operation. Large scale mines, with associated processing, tend to have substantially higher output labor-ratios than small or medium sized mines.¹¹ In terms of job creation, small and medium scale mining, where feasible, may be more desirable than poorly mechanised open pit operations.

In Macalder, most youth use mining as a springboard to other economic activities, with the youth engaging in mining activities in order to obtain money (as shown in Plate 6.1). Most women and the youth engage in mining activities such as ore crushing and manual sorting of stones, which provides a form of employment for the women and youth. The money they earn is spent on other economic activities, which include setting up of kiosks and the purchasing motorcycles, which they use as *Boda Boda* operators (local motorcycle transportation). Thus mining acts as source of employment directly and indirectly.

The employment provided by ASM has: helped lower crime and suicide rates in rural areas; assisted in raising living standards; and minimised rural-urban migration from ASM areas. ASM has contributed significantly to the provision of financial support to local agriculture, the construction of bridges and roads, education, and rural collective welfare projects, among other things.

- Supply of raw materials to local industry

Gold reaches designers in the country, who, after smelting and other impurity removal processes, use it to make rings and necklaces for local consumption. This has provided good returns for both miners and designers, thus contributing to the development of the local industry. However most of the earnings are taken by the middlemen. In Figure 6.2, it can be seen that gold production in Kenya (shilling value) has increased over the years, which means that gold has been the most sought-after mineral in the country, despite the dwindling deposits. As can be seen, it is still very important in Kenya and gold is still much sought after as a raw material.



Plate 6.2: A youth shows his working station in the area.

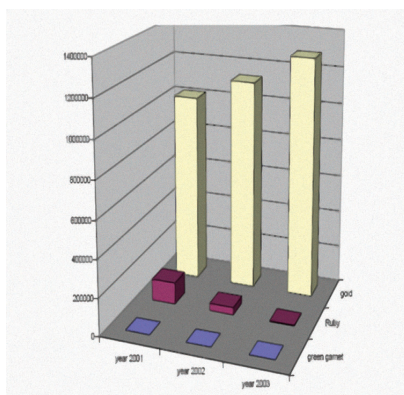


Figure 6.3: Value (in KES) of gold and gemstones produced - 2001 to 2003¹²

- Poverty alleviation and alternative livelihoods

ASM plays a pivotal role in alleviating poverty and promoting local economic development in mining areas. In 1998, ASM in China generated RMB 4.36 billion (USD 0.5 billion) in profits and contributed RMB 44.07 billion (USD 5.3 billion) in tax revenue.¹³

Macalder is an arid area, with only one rainy season. Fishing is done on Lake Victoria and small-scale mining becomes the next best alternative for earning a livelihood. The earnings from mining allow individuals to put their children in school and buy household and other domestic items. Some individuals have managed to buy cars with earnings from mining and it therefore helps to alleviate poverty. One miner reported selling gold worth KES 400,000 (USD 4,700)! This is a lot of money in a rural area and it can be used in many economic and social activities.

- Development of infrastructure and social facilities

Mining activities in Kenya have had many implications, including the setting up of the Gogo Power Station, which produces 1000kw per unit, using two units of the Kaplan Turbine type. The station was commissioned in 1957 and is now about 60 years old. The main reason for the installation was to supply South Nyanza Mine at Macalder. A road that passes through most of the interior is a result of the continued exploration, and bridges and other road maintenance projects are all associated with gold being available in this region. A school was set up in Macalder (which is still in operation) and through KenGen (located at Gogo Power Station), well performing pupils and students receive various scholarships (up to university level). There is a district hospital in Macalder, Administrative offices have been built.

- Negative Impact of Mining in the Macalder Area

Seven selected cases of negative aspects of ASM are listed below.

- ASM operations are often illegal and they can encroach onto concessions in the formal mining sector, leading to safety hazards because of undermining existing workings while high-grading the deposit. Moreover, they often have an extremely poor safety record, evade taxes and can cause a host of environmental problems.
- Since mining involves the exploitation of non-renewable resources, once the ore body is mined out, or the market disappears, there is nothing left. Many deep holes have been left in the Macalder area, with the deepest in Masara.
- The employment, income and production generated from ASM often come with significant cost to the health, safety and environment. ASM hazards are many and varied, including: poor ground conditions, leading to underground tunnel failure, methane or coal dust explosions from coal mines, flooding, machinery accidents, poor lighting and ventilation, explosives accidents, and electrocution. Hydraulic monitoring of secondary deposits can also prove unsafe, as there is potential to undercut a hill slope and generate a landslide.
- Endemic problems include the fine dust from mineral processing, which leads to silicosis, and noise pollution. ASM accidents are often under-reported, due to the illegal or semi-legal status of most ASM operations: it was estimated that non-fatal accidents in ASM operations are 6–7 times higher than in the formal mining sector.¹⁴
- In the Macalder area, ASM operations lead to the destruction of arable and grazing land, through: excavation, accelerated erosion of top soil, landslides, the collapse of old workings, unsafe tailings disposal methods, the lowering of water tables, soil contamination (due to dust from mines and tailings), and increased levels of sediment load and flooding in nearby rivers.

- ASM has been associated with a host of negative social impacts, especially in the boomtowns that spring up following big mineral finds in remote locations. These include challenges such as prostitution, substance abuse and gambling. Women and children are disproportionately affected by these factors.
- The operations are regulated by the same legislation (i.e. for the environment, labour, mineral rights, exploration and permitting) as the formal mining industry. ASM compliance is generally low, due to low education, lack of finance, and poor technology available to the miners.

- **Negative Environmental Impacts**

In the Macalder gold mining area, the ASM operations result in a range of negative environmental effects. Some of these are outlined below.

- **Soil and water pollution**

Most small-scale mining operations in the area increase sedimentation in rivers, especially through the use of hydraulic pumps and suction dredges. By blasting hillsides with water under high pressure, hydraulic pumps leave scars on the landscape, which may take years to develop even the lightest covering of vegetation. Deforestation, which contributes to erosion and loss of fauna, is also associated with small-scale mining, because a lot of firewood is used in the process.

Since most small-scale miners do not preserve the topsoil that is removed before excavation begins, this topsoil is often washed away into surface water, carrying with it ecologically valuable seed banks that are necessary for the regeneration of vegetation. In addition, few small-scale miners engage in reclamation or post-mining recovery practices, especially if the piece of land belongs to the miner.

- **Damage from mercury use**

Mercury (Hg), cyanide and other hazardous chemicals are used as reagents for recovering and purifying gold and other precious metals. Small-scale gold mining is a significant source of Hg being released into the environment, with as much as 800 tons/yr of metallic mercury being released into the environment worldwide.¹⁵ Every year, about 120 to 240 tons of mercury is released into the environment in China alone, due to gold amalgamation operations.¹⁶

The use of mercury in small-scale mining has health and environmental effects that have yet to be fully studied and documented. Mercury is discharged into the environment (when miners fail to recover mercury tailings), either by dumping waste directly into rivers or by releasing mercury vapor into the atmosphere when the mercury-gold compound is burned. Small-scale miners use inorganic mercury (see Plate 6.2), which is often converted into toxic organic and inorganic compounds through natural processes. Of greatest concern is the highly toxic organic compound, methyl

mercury, which forms in rivers and lakes when micro-organisms metabolise metallic mercury. This toxic form of mercury then accumulates in fish and, when ingested, causes mercury poisoning in humans. Metallic or inorganic mercury can also be hazardous if it is transformed from its liquid state into gas. Although symptoms differ with poisoning by inorganic and organic mercury, both kinds may result in nervous system disorders, birth defects, or death.



Plate 6.4: A miner shows a sample of mercury unaware of its health hazards

The study of gold sites in the Migori Gold Belt in Kenya, revealed that the concentration of heavy metals (mainly Hg, Pb and As) are above acceptable levels.¹⁷

Mercury has a long residence time in the environment and this makes its emission from artisanal mining a threat to health. The major health hazards among miners are: inhaling large amounts of siliceous dust; careless handling of mercury during gold panning and Au/Hg amalgam processing; water logged pits and trenches; and large number of miners sharing poor quality air in the mines. The amount of mercury used by miners for gold amalgamation during peak mining periods varies from 150 kg to 200 kg per month. Of this, about 40 per cent is lost during panning and 60 per cent is lost during heating Au/Hg amalgam. The use of pressure burners to weaken the reef is a deadly mining procedure, as hot particles of Pb, As and other sulphide minerals burn the body, and burns may become septic. This, apparently, leads to death within 2–3 years.¹⁸

Mining methods in the Macalder involve excavation of the ground for the purposes of extracting minerals, building stone and sand. In addition, the potential negative environmental impacts by mining and quarrying activities include:

- Degradation of air and visibility because of airborne particles;
- Noise and vibrations, leading to disturbance of humans and wildlife, and damage to structures (including houses, in certain instances);
- The existence of dangerous open shafts, some as deep as 31 m and which are linked to underground tunnels, which pose a danger to local inhabitants and their livestock;
- Abandoned large open pits (see Plate 6.3) have become a breeding ground for mosquitoes;
- Atmospheric pollution of dust that is rich in silica, which arises from manual pounding of the gold-bearing ore, may cause various respiratory complications (such as silicosis);
- Mass wasting of land on slopes (see Plate 6.4), as a result of poor mining practices;
- Panning, this takes place in flowing streams and contributes to the contamination of water and the siltation of riverbeds (Plate 6.5).



Plate 6.5: Abandoned open cast mine has filled with water, are a risk to people and animals



Plate 6.6: Landslides on slopes caused by gold mining activity



Plate 6.7: Panning along flowing streams results in contamination of river water

Other Constraints and Challenges of Gold Mining in the Macalder Area

Currently, the mineral sector operates in terms of the Mining Act, which was put in place in the 1940s. The Act is considered by investors as an impediment to mining activity, which has prompted the government to initiate its overhaul, in order to: make investment in mining more attractive; address environmental concerns. This should attract more investors, particularly local small-scale miners, while ensuring sustainable exploitation of mineral resources and the environment. One of the greatest challenges facing the mining sector is the lack of economic incentives which would assist in the rehabilitation efforts. Appropriate economic instruments for the sector would ensure definition of property rights, charges and fees, and insurance bonds and the creation of a market.

Very little rehabilitation works have been undertaken on old mines in the country, due to a lack of clear regulatory tools and mechanisms. The enforcement of relevant provisions of EMCA (1999) will go a long way in managing negative impacts of mining, quarrying and sand harvesting. Some old quarries and mines have been reclaimed and restored close to the original state through replanting of appropriate tree species.

In Kenya, such a rehabilitation effort has been undertaken by Bamburi Cement Company in Mombasa, which turned the mined areas into an excellent tourist site (Haller Park). This is an example of what should be done by all mining operators. The newly reclaimed mined areas could be used as sources of firewood, for fish ponds and as livestock watering points. This is the responsibility of individual mine owners, local authorities who license them and the various government ministries.

Policy and Legislation Alternatives to Improve Small-Scale Mining

The ASM academic literature frequently highlights policy alternatives¹⁹ intended to improve the overall situation for miners. The international community could

do much more to improve sustainability in the ASM industry by: (1) legalising ASM and implementing sector-specific legislation; (2) contributing to community development and providing increased economic support; (3) providing training and educational assistance, and playing an expanded role in the dissemination and transfer of important technologies.²⁰

In India, it has been seen that implementing educational and training initiatives could facilitate additional environmental improvement at sites; while in Brazil, it has been suggested that the following steps should be taken, in order to mitigate the impact of ASM:

- improving coordination among public entities responsible for control of the ASM sector;
- undertaking environmental management and reclamation initiatives;
- carrying out research and diffusing mining and environmental technology;
- developing and implementing appropriate licensing procedures for ASM;
- reviewing environmental impact evaluation and enforcement procedures; and
- improving regional planning.

In Zambia, institutions responsible for managing the environment are unable to effectively carry out regulatory and monitoring mandates, due to inadequate resources, and it is recommended that all mining activities, including ASM, should submit environmental impact assessment reports before a license to mine or explore is granted.

In Bolivia, a preliminary strategy to move against social inequity in ASM has been established.²¹ This strategy mainly revolves around implementing alternative sustainable livelihood options, with the participation of the government (central and local), the private sector, NGOs and donors (as facilitators and partners). It aims to reduce the number of families eking out a living from artisanal mining, in order to enhance the viability of ASM.

A series of strategies for improving environmental performance in the small-scale gold mining industry were reviewed²² and it was concluded that while conditions varied regionally, few regulations and policies exist specifically for small-scale gold mining activity in developing countries. It was argued that a combination of policy, management and technology related initiatives are needed to facilitate environmental improvement in the industry.²³

In a handful of countries, legislation has been implemented in an attempt to address some of the concerns mentioned above. A pilot study conducted on ASM legislation argued that a growing number of developing countries were introducing laws and regulations for their ASM sectors, but that these had not necessarily helped to promote the growth of the sector, and had not made significant improvements to the social and environmental problems associated with the sector.²⁴

Since 1989, when ASM in Ghana was legalised, a lot of interest had been generated in the sector, because of its socio-economic benefits. However, owing to a

lack of the necessary training and inadequate finances on the part of small-scale operators, most operations are poorly managed in terms of environmental management.²⁵ A more positive example is the Department of Mining in Papua New Guinea, which has become a proactive source of educational activities and information gathering for ASM, leading to the creation of a comprehensive development plan for the sector. This has resulted in a tripartite programme, with active participation from a number of donor agencies, and a private sector that promotes integrated rural development, and takes into account the important economic and environmental aspects that are vital for effective poverty alleviation.

Specifically, the government should encourage the formation of trade groups, which would help to pool resources and assist artisanal miners to buy mining equipment, which is expensive. Furthermore the need for middlemen would be reduced and more cash retained by the miners.

Mining legislation should reduce risk and uncertainty for potential investors. Economic adjustment programmes should ensure easy access to exploration permits and mining concessions. A truly sustainable approach to mining development calls for substantial change in attitude towards the environment, especially in preparation and management of the related activities. The District planning office must recognise that socio-economic prosperity in the Macalder area depends on a high quality environment and losses due to gold mining can reduce the living standard of people. Therefore, sustained effort should be made to promote environmental awareness among the population, provide training for resource managers and motivation for environmental action. Permits and concessions should be transferrable, with minimum government interference. Investment agreements, where required, should be market based and should provide additional assurances, in order to protect the investor from unwarranted government interference, and provide additional safeguards for Government to ensure that investors live up to their obligations.

On-site training of miners on safe mining practices should be encouraged. The use of dust masks, air filters and heavy chemical-resistant gloves for use during mining and mineral processing should be provided by the government. Miners should be advised to purchase such protective gear and to continue using it for the sake of their health. This could best be achieved by holding frequent workshops for miners. This is likely to bear fruit in terms of information dissemination and knowledge of diseases. The Migori District Commissioner and other Government officials, including medical officers and the chief geologist, should organize such workshops in order to harmonise the mining industry and make it conform to the legislation and environmental policies.

The Government should consider setting up a clinic at Masara, which is one of the mining centers in the district. This would improve the health of the mining community. Although there is a sub-district hospital in Macalder, a unit that deals

with mercury and other heavy metal poisoning should be set up (a detailed study is currently being undertaken on heavy metal poisoning in the area).²⁶ This unit should assist in advising patients and conducting other health workshops for the community. For instance, artisanal miners should be encouraged and taught how to use magnets to isolate the gold – a mercury-free technique used in gold mining in Mozambique.²⁷

Finally, since artisanal mining provides basic geological information to industrial mining concerns, it can be considered a first step in exploration. Consequently, with the help of private developers, intensive geological research should be conducted, not only in terms of gold exploration, but also for other gemstones, including diamonds, because this is the same geological province in which diamonds and other gemstones are found in neighboring Tanzania.

Conclusion

Mining is an indispensable economic activity and it has been the driver of much economic development of many countries. The tangible, short-term benefits provided to communities by ASM are outweighed by the costs in terms of illness, injury, pollution, waste of natural resources and market distortion.²⁸

In some countries,²⁹ the contribution of ASM may outweigh its negative impact, especially if the central government makes more effort to regulate, guide and encourage the development of the industry, and create a sound environment for its operators. An appropriate system of laws, regulations and suitable institutional structures are required for effective management of small-scale mines.³⁰

ASM contributes significantly to the supply and utilisation of resources; initiates market competition in the resource sector; reduces transportation bottlenecks; and contributes to rural economy. ASM in Kenya has had rapid development in the past and has contributed significantly to the development of the economy. In the medium term at least, it is certain that ASM will continue to play a crucial role in Kenya's mining industry. A policy for ASM can only be implemented effectively if the interests of most or all relevant parties are addressed adequately.

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Part II

Hydrometeorological Hazards

CHAPTER 7

Storm Hazards in Sub-Saharan Africa

Christopher James Charles Reason

Introduction

Random, air mass thunderstorms are a frequent occurrence during the rainy season over many parts of Africa. These convective storms result from local instability within a sufficiently moist air mass, with regional surface heating, land surface gradients and topography often playing a role in their initiation. Hail, lightning strikes, gusty winds and tornadoes may be associated with severe thunderstorms. In some cases, the convection is organised into identifiable linear or quasi-circular systems of considerable size, which have a longer life cycle than air mass thunderstorms and which tend to produce heavy rainfall over a relatively large area. Examples of such organised convective storms are tropical cyclones, tropical – extra-tropical cloud bands (also known as ‘tropical temperate troughs’), intense mid-latitude cyclones (cut-off lows) and mesoscale convective complexes (MCCs). A general expectation under climate change scenarios is that the hydrological cycle may intensify, leading to more cases of severe storms in the future.

In the African context, tropical cyclones are mainly confined to two regions. The first is the southwest Indian Ocean, its islands (e.g. Madagascar and Mauritius) and the southeastern mainland (essentially Mozambique). The West African coast and adjacent tropical North Atlantic is the second major region of tropical cyclone occurrence in the African sector (where they are officially referred to as ‘hurricanes’). An important difference is that hurricanes tend to move away from West Africa towards the open ocean whereas tropical cyclones tend to generate east of Madagascar and then propagate towards that island (and sometimes as far as Mozambique) often causing loss of life and devastation.

Tropical – extra-tropical cloud bands are the most important synoptic rainfall-producing system during the summer half of the year over much of sub-tropical southern Africa.¹ They connect a tropical disturbance somewhere over tropical southern Africa with a westerly disturbance (such as a cold front) passing south of the landmass; and can be seen on satellite imagery as a band of cloud that is oriented from the northwest towards the southeast.

Intense mid-latitude westerly systems, and in particular cut-off lows, are of importance in the poleward margins of the continent (mainly South Africa in the far south and the Mediterranean countries of Africa in the far north), although associated frontal systems and weather changes may sometimes penetrate quite deeply into the tropics. Cut-off lows, which can form when an area of cold, mid-latitude air is isolated or cut off from the main westerly flow, are responsible for almost all of South Africa's flood disasters. They are also important contributors to rainfall in northwest Africa, particularly in the Atlas Mountain regions.²

MCCs occur in many parts of sub-Saharan Africa where the local moisture sources are sufficient to fuel their development. These are quasi-circular storm systems, with an interior cold cloud shield at a temperature colder than -52°C , that occur over an area of at least 50 000 km² for at least six hours.³ The very cold cloud shield implies deep convection and heavy rainfall. Prominent areas of occurrence are tropical West Africa, the Congo Basin and southeastern Africa, particularly Mozambique and the KwaZulu-Natal and Lowveld regions of South Africa.⁴

ENSO influences on organised convective systems

Although it is well known that the El Niño (La Niña) mature phase of the El Niño Southern Oscillation (ENSO) climate mode tends to be associated with below (above) average summer rainfall over many parts of southern Africa,^{5,6} the relationship between this mode of climate variability and the frequency of particular types of storm system is not well understood. Seasonal changes in rainfall may result from anomalies in the frequency of storms, the strength of storms, the track of storms or a combination of these factors. One of the difficulties in determining ENSO influences on storm characteristics is being able to monitor and detect the various types of storms over a sufficiently long enough period to build robust statistics. This problem is hardest for the MCC storms category, as these storms are generally smaller in size and shorter in duration than cut-off lows or tropical cyclones.

For MCCs, a climatology over sub-tropical southern Africa of 70 cases during the 1998-2006 period was derived using the maximum spatial correlation technique (MASCOTTE) applied to brightness temperature data derived from European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) images.⁷ An automated cloud band-detection scheme applied to outgoing long-wave radiation data for 1979-2011 identified 821 tropical – extra-tropical cloud band events.^{8,9} For cut-off lows, analysis¹⁰ of 30 years of National Center for Environmental Prediction (NCEP 1) re-analysis data at the 200 hPa level led to the identification of a total of 337 systems occurring over Africa south of 20°S.

Compiling tropical cyclone statistics in the southern African/southwest Indian Ocean region is more straightforward,¹¹ since this information is already derived by the Regional Specialised Meteorological Centre at La Reunion and the Joint Typhoon

Warning Center in Hawaii. A total of 293 such storms occurred in the 0–40°S, 30–100°E region during the 1980–2007 period. It has been argued¹² that a likelihood exists of more intense tropical cyclones in the future, but that the total number of tropical cyclones may decrease.

A La Niña influence on frequency of cut-off lows has been suggested.¹³ It was noted that out of seven strong La Niña events during the 1973–2002 period five of the mature-phase years experienced well-above average numbers of cut-off lows and only the 1999 event was associated with well-below average numbers. For tropical cyclones, the most obvious La Niña influence concerns track and landfall in Mozambique. It has been shown that landfall of tropical cyclones on the Mozambican coast tends to occur only during La Niña seasons.^{14,15} An influence of ENSO on track is also apparent for tropical – extra-tropical cloud bands, with such systems more likely to be located: over the southern African landmass during La Niña years; and offshore over the southwest Indian Ocean during El Niño.¹⁶

Although most years with low numbers of cloud bands over the landmass correspond to El Niño years, the reverse is not strictly true for La Niña.¹⁷ However, what is clear is that the seasonal cycle is suppressed (enhanced) during El Niño (La Niña) so that the peak in cloud-band occurrence over southern Africa occurs in December (November) during El Niño (La Niña) and the last month of occurrence is March (May).¹⁸ For MCCs, the record is too short to make a definitive statement; however, both the 1999/2000 and 2005/06 La Niña summers had an above-average MCC frequency (18 and 9 respectively), whereas only four MCCs occurred over southern Africa during the 2002/03 El Niño summer.

On longer time scales, it is expected that the extra-tropical storm tracks in each hemisphere will shift polewards under climate change scenarios. Thus, it seems likely that the frequency of cloud bands, MCCs and cut-off lows over southern Africa and over North Africa may change in the future.

Circulation impacts conducive for organised convective systems

In order for deep convection and storm development to occur, there must be significant uplift of moist air through the lower- and middle troposphere. Regarding uplift, a composite of omega or pressure tendency at the 500 hPa level for 15 La Niña events since 1950 shows a large band of negative values (or increased uplift) over much of southern Africa during the summer (Figure 7.1). Thus, conditions in the middle troposphere are more conducive for convection (and hence storm development) than average during La Niña summers. There are also low-level easterly wind anomalies over most of the region and adjacent southwest Indian Ocean, implying more advection of moist marine air from this oceanic moisture source during La Niña summers (Figure 7.2).

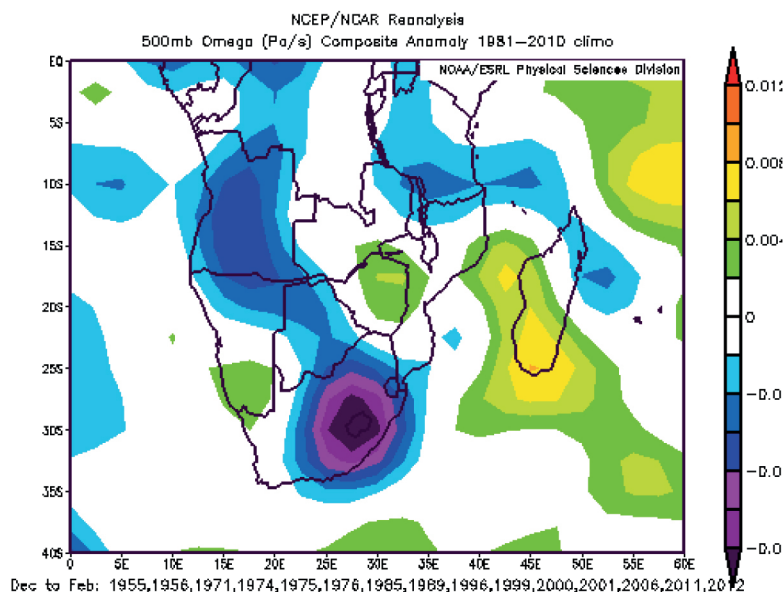


Figure 7.1: Composite of omega (pressure tendency) at the 500 hPa level for 15 strong La Niña events since 1950 (contour interval 0.005 Pa s⁻¹). Source: Author

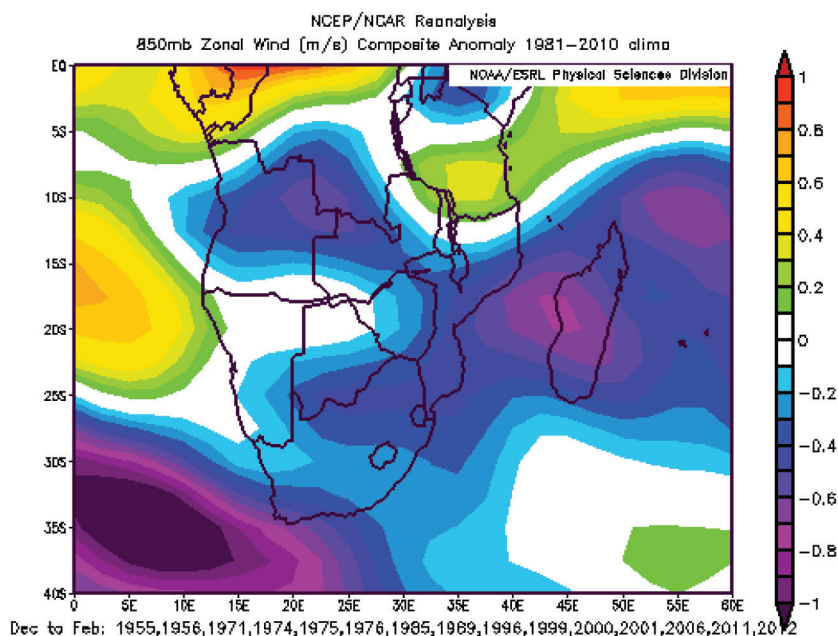


Figure 7.2: Composite of zonal wind at the 850 hPa level for 15 strong La Niña events since 1950 (contour interval 0.1 ms⁻¹). Source: Author

Another parameter of interest is vertical wind shear in the lower- to middle troposphere. Large values of this parameter are unfavourable for deep convection, since the winds above the surface would then tend to divert unstable air rising from the surface away from its source and prevent the vertical development of cloud. A correlation of the Niño 3.4 index (widely accepted as a useful measure of ENSO activity) for summer shows strong positive correlations over much of sub-tropical southern Africa and the neighbouring oceans (Figure 7.3). Values of greater than 0.3 are statistically significant at 95 per cent. Thus, Figure 7.3 indicates that there is decreased vertical wind shear (favourable for storm development) during summer, with negative values of the Niño 3.4 index; i.e. La Niña summers.

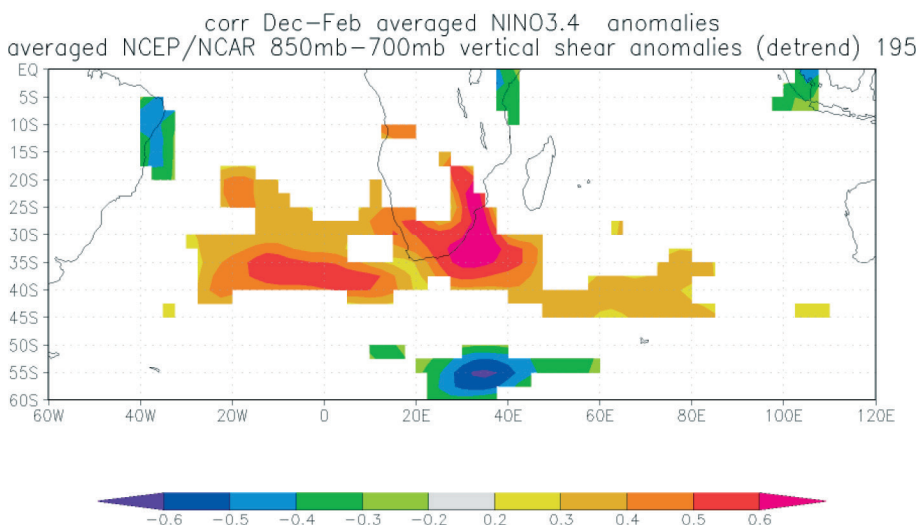


Figure 7.3: Correlation between the Niño 3.4 index and 850-700 hPa vertical shear (contour interval 0.1). Source: Author

Figure 7.4 shows the correlation of the Niño 3.4 index with 2–7-day variance in 200 hPa geopotential height. The latter field represents synoptic storm activity and is greater (lower) than average when there is more (less) storm activity in a particular region. Again, values that are greater than 0.3 are statistically significant at 95 per cent. Thus, Figure 7.4 implies increased mid-latitude storm activity over southern South Africa and the neighbouring oceans during La Niña summers, which is consistent with the increased number of cut-off lows previously noted during these events.¹⁹ Increased 200 hPa variance in the regions shown in Figure 7.4 would also imply increased mid-latitude cold fronts passing through the region during these summers and therefore would also be favourable for increased cloud band activity and hence rainfall during La Niña summers.

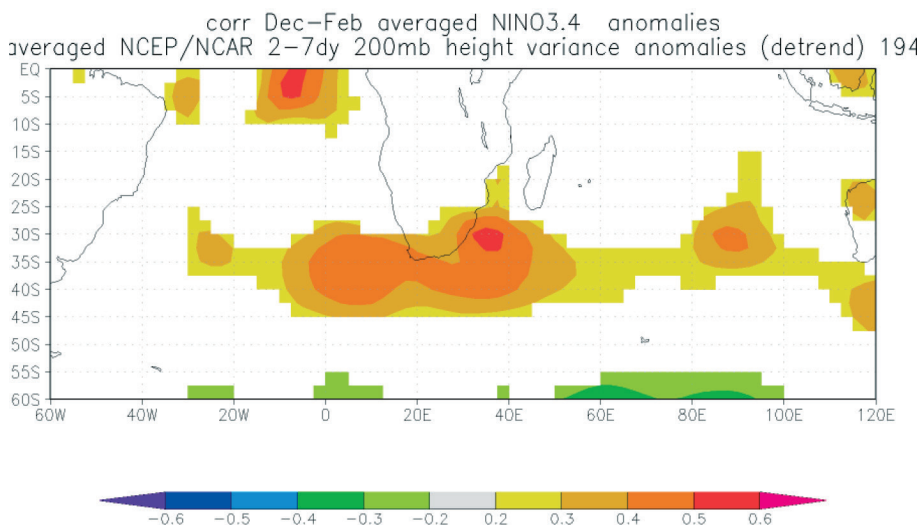


Figure 7.4: Correlation between the Niño 3.4 index and 200 hPa 2-7-day geopotential height variance (contour interval 0.1). Source: Author

Summary

Although it is well known that La Niña (El Niño) events tend to be associated with above (below) average rainfall over southern Africa,^{20,21} relationships with the various rainfall-producing weather systems are less well understood. However, there are important changes to regional circulation that are considerably more favourable for storm development during La Niña summers than other summers. Taken together, these changes help to explain why there tend to be more cut-off lows, MCCs and cloud bands over sub-tropical southern Africa during La Niña seasons.

Although it might be thought that it is better for agricultural purposes for a growing season to receive above-average rainfall, rather than average or below-average rainfall, it is the timing of the rainfall that is crucial for maturation of the crop and harvesting. In general, a season that has more uniformly spread rainfall of moderate amounts is preferable to one that may have well-above average rainfall, but where it is made up of a few events of intense precipitation. Furthermore, the risk of flash flooding tends to increase during La Niña summers, posing challenges not just for farmers but also (more broadly) for water resource managers, municipalities and populations that live in vulnerable areas.

On longer time scales, climate change scenarios suggest that the chance of more extreme events, including floods, is likely to increase. Similarly, the chance of more intense tropical cyclones, including those that threaten Africa, is projected to increase, although the total number of cyclones may decrease.

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CHAPTER 8

Occurrence and Effects of Drought in Sub-Saharan Africa

Ellis Mbaka Njoka

Background Information

Africa experiences a wide range of natural and human-induced hazards and disasters, which cause extensive damage to human and animal life, property and infrastructure. Hydro-meteorological hazards are the most common disasters in sub-Saharan Africa and they are wide-spread. They include tropical cyclones, wildfires, storm wave surges, extreme high temperatures (global warming), drought, sand or dust storms, landslides, avalanches and floods. They constituted about 59 per cent of natural disasters in sub-Saharan Africa in the years 1975-2002.

Reducing hazards through deterrent means is of primary concern for continued development in the Sahel. From the seventeenth Century, sub-Saharan Africa has experienced numerous droughts, which are occurring at increasing frequencies. Severe dryness in the 1910s, 1940s, 1970s and 1980s was accompanied by famine in the region. From 1972 to 1984, many people died while over 750 000 others (in the same region) were dependent on famine relief in 1974.

With climate change, drought and floods are expected to increase in frequency and intensity in the dry lands. However, data limitations mean that temporal and spatial uncertainties persist regarding the nature of changes in climate. How such changes will influence the rate of recurrence and the number of excessive climate episodes (such as dryness and floods) is also uncertain. While ongoing efforts to improve the climate database and quality of climate data may provide better projections, a resilience approach that focuses on enhancing adaptive capacity to dealing with change and uncertainty holds promise for identifying options for adaptation to drought

Definition of Drought

Any description of drought focuses on shortage of water. Generally, drought is a prolonged period of water deficit, which could be a season, a year or more, relative

to an expected mean over years. A more inclusive description of drought involves socio-economic, meteorological, hydrological and agricultural forms of drought.

People mean different things when they talk of drought. This often typifies who they are, the work that they do and their perspective. For example, farmers and ranchers are concerned about agricultural drought while urban planners are concerned with hydrological drought. Hydrological drought is the form of drought most commonly referred to as it is the most familiar and is easily identified by most people.

The absence of an exact and globally agreed on description of drought makes it difficult to declare the existence of a drought. The thresholds for asserting drought are haphazard in many cases and hence it is difficult to provide a universally accepted definition.

The National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service of the United States describe drought as 'a time of unusually long dry weather due to lack of water'.

Since there is no globally agreed definition of drought, the nature of drought means that its definition is usually application-specific in relation to the region under study. In numerous studies, drought is defined in terms of its climatological/ meteorological, hydrological, agricultural, economic and socio-economic contexts. These dimensions of drought also determine the type of drought being defined.

- 1 Climatologically, drought can simply be expressed in terms of rainfall deficit, in relation to some mean amount and the period of dryness. The most commonly agreed on definition of drought is that it is an 'interval of months or years during which actual moisture in a given area falls below the expected minimum'.¹
- 2 From a socio-economic perspective, 'drought' refers to a prolonged and substantial, discouraging deviation in precipitation in comparison with the amount of precipitation the community expects.²
'Drought conditions' generally refer to: agricultural, meteorological and hydrological forms of drought as specified below.
- 3 Meteorological drought occurs when there is a prolonged episode of below normal rainfall, which presents as a natural shortage of water.
- 4 Agricultural drought occurs because of a shortage of moisture to support average crop production and/or grasses in the rangelands. This form of drought can also occur in periods of average rainfall when soil conditions and agricultural techniques require more moisture.
- 5 Hydrological drought takes place when water reserves fall below an established statistical average in aquifers, lakes and reservoirs. In addition, hydrological drought can happen at times of average or above average rainfall where human requirement for water increases and usage lowers water reserves.
- 6 Drought is an unusual recurrent happening of weather variability; it is common in all climatic regimes. It is a brief anomaly in a given climate while aridity is a long-lasting occurrence of certain weather variability, which can be seasonal.

Causes of Drought according to Local Knowledge Systems

Table 8.1 presents information from surveys and studies on the perception of smallholder farmers on the causes of drought^{3,4,5,6} in order of importance.

Table 8.1: Perceived causes of drought

Perceived Cause of Drought	Explanation/Examples
Teleological constructs: define drought as attributable to supernatural powers.	God's will People's sins Traditional – spirits
Meteorological/physical constructs that associate causes with physical or weather processes.	Movement and position of the sun, moon and stars Climate change Dry winds
Anthropogenic constructs	Witchcraft, rainmaker, medicine man/woman Environmental degradation (cutting down trees, pollution, soil erosion)
Unascertained constructs.	I do not know.

An examination of the perceived causes of drought presented in Table 8.1 suggests that smallholder farmers have limited knowledge of the physical processes that govern weather and climate. Over 50 per cent of farmers in all surveys consulted believed that teleological constructs were the cause of drought. The action taken by these farmers in response to drought is expected to be guided by their perceptions of the cause of drought. This was confirmed from responses to questionnaires on how drought can be controlled.^{7,8,9} The options chosen by respondents were praying and offering sacrifices, doing nothing and letting fate take its course. Farmers also expected the government to control the drought hazard. While such responses may be valid, they may exacerbate individual vulnerabilities to drought.

Perceptions of Drought Risk and Hazard

The perception of drought risk by individual actors and their societies is crucial for understanding their inaction or action to reduce their vulnerability to drought. Perceptions about drought influence the way decisions are made and what action is taken. Perceptions regarding drought can differ from one group to another, based on individual or group characteristics and knowledge about the hazard. Therefore, perceptions about drought are qualitative and subject to value judgements.

Various stakeholders are involved in the decision-making process, from the individual to households, communities, political representatives, scientists/experts, media and managers. The individual interests of each stakeholder affect his/her perceptions. A climatologist may be interested in the climatic risk aspect of drought, in order to acquire information that can be used in early warning systems. A social

scientist, on the other hand, may be more concerned about how livelihoods could be managed to withstand and improve from the bad consequences of climate variability. Both experts may work on data, which may or may not be of sufficient quality and quantity for them to extract the information they need.

After gathering facts, experts provide technical advice to politicians, who enact laws for the general public. This may be why short-term mitigation projects, which can be implemented within the legislative period, are given priority over long-term projects, which run for longer periods.

The qualitative attributes of a risk are usually considered more important than the quantitative aspects of that risk; for example, the picture of an emaciated mother with her starving child and the conjecture related to it have greater impact on influencing action.¹⁰

Causes of Drought in Sub-Saharan Africa

In sub-Saharan Africa, drought can be defined as occurring when excessive heat accumulates on the earth's surface causing meteorological changes and declining cloud cover. This results in greater evaporation rates. The effects of drought are exacerbated by anthropogenic activities, which reduce the water-holding capacities of the soil and lead to soil degradation.

- 1 The climate of East Africa is characterised by monsoons, sub-tropical anti-cyclones and African jet streams, including easterly/westerly waves and the Inter-Tropical Convergence Zone.^{11,12} The bimodal rainfall regime of the East African dry lands is due to the movement of the Inter-Tropical Convergence Zone to the south and north. Rainfall variability in amounts, time and place is quite common.
- 2 In equatorial East Africa, rainfall conditions in the Indian Ocean are affected by activities of tropical cyclones. These cyclones can cause drought over the regions outside the cyclone area, even though they are associated with intensive rainfall in the area of occurrence.

Lessons can be learnt from the names given to specific droughts, as they also highlight the non-drought factors that trigger food scarcity and livelihood insecurity. For example, the drought of 1981 was named 'Yuaya Nukwangwete', meaning 'famine with cash in my pocket'. This refers to a simultaneous drought and market failure, as people had resources but could not acquire food through purchases.

This also implies that functioning markets, existing adaptive capacities and good governance of resources should be encouraged. These include but are not limited to strategic grain reserves or timely imports that can deal effectively with drought impacts such as food scarcity. However, droughts continue to cause widespread crop and livestock loss and contribute to food scarcity (adding to other non-drought

causes), which led the Kenyan government to declare a drought disaster and to appeal for international assistance in 2000, 2005 and 2009.

Drought Characteristics and Indices

Drought is said to occur when rainfall is significantly less than expected in a given area. There are two types of drought: short-term drought and long-term drought. Short-term drought is experienced when there is one season of hot and dry weather and the level of the rainfall received is an indicator of the likely period of dryness.

Long-term drought can entail many seasons or years of deficit precipitation. It normally begins with relatively less-than-average rainfall seasons, which culminate in a major drought. Prolonged drought, although not very common, requires national or regional monitoring of the weather.

Characteristics of Drought

Drought is a result of temporary periodic change in a rainfall regime. Monitoring of rainfall trends and periodicities and of land cover may indicate the onset of a drought. These variables are used in predicting the possibility of a dry season.

Drought has three characteristics: spatial coverage, intensity and duration. 'Intensity' refers to the level of the rainfall deficit and/or seriousness of effects related to the deficit. Drought is usually computed by the deviation of some climatic indicators from normal and is closely linked to duration in the determination of its impact.¹³

Duration is another distinguishing characteristic of drought. Although the start of a drought is difficult to pinpoint, it can last for many months or years. The severity of drought effects depends on the onset of the rainfall deficit (e.g. in relation to the crop calendar) and the intensity and duration of the drought.

Weather variation is distinguished by its spatial nature. The location disturbed by harsh drought changes progressively, as drought shifts from one area to another. This means that drought can be described in relation to:

- Rainfall deficit (resulting in a lack of moisture for crop production);
- Deviation from an average rainfall value;
- Duration of the dry period.

Indices

It is difficult to identify the exact beginning and gravity of a drought. The spread extent of drought is normally much greater than for other natural hazards, making evaluation and response arrangements rather difficult because effects spread over expansive areas. Droughts may also be localised without the wider public taking notice.

Impact of Drought

In sub-Saharan Africa, drought is responsible for 80 per cent of loss of life and 70 per cent of economic losses linked to natural hazards. For example, in Zimbabwe, a 45 per cent drop in agricultural production, a 62 per cent decline in the value of the stock market, a 9 per cent drop in manufacturing output and a GDP drop of 11 per cent were experienced as a result of the drought of 1990/91. In the drought of 1999-2001, Kenya lost a whopping 2.5 billion dollars. This was a great loss to the national economy and resulted in the failure to develop necessary infrastructure such as schools and hospitals.

The consequence of drought is famine, with food aid to the continent accounting for nearly 50 per cent of the global food aid programme. The constant drought in southern Africa since 2001 has resulted in major food shortages. The severe drought in the Horn of Africa in 2002 led to 3.2 million people in Kenya becoming dependent on food aid, with malnutrition reaching 40 per cent of the population. In 2005, many other African countries had a food deficit owing to the combined effects of serious dryness.¹⁴ Most of these nations had had more than 10 years of poor harvest.

In Africa, water non-availability is anticipated to become one of the greatest deterrents to economic growth in years to come. Declining levels of yearly water precipitation and its run-off would promote desertification of countries in southern Africa. This sub-region could experience a further decline in river and stream flows, which could reduce the ability of groundwater to 'recharge'. This would mean that the source of water would be insufficient to maintain the current level of food production from irrigated agriculture. To maintain their needs, water would have to be reduced from agriculture, which would cause the affected nations to depend on imported food. By the year 2025, 25 countries in this region are anticipated to be water stressed.¹⁵

Most scenarios estimate a river flow decrease of more than 7.5 per cent by 2100. If this decrease exceeds 20 per cent, it will have a big impact by interfering with normal irrigation. This scenario would create conflict because of the negotiated allocation of water during periods of high flow and would affect agricultural production. In terms of the Nile region, most scenarios estimate a decrease in river flow of more than 7.5 per cent by the year 2100.

Impact on Biodiversity

Biodiversity within environments underpins ecosystem amenities that are crucial for maintenance of populations in Africa. It is the lifeline for continuous development in the region and the world. The dry areas of the world are the home of most important cereal crops and food legumes; for example, barley, wheat, fava beans and lentils. Sufficient evidence exists that drought, exacerbated by climate variability, will have a destructive effect on ecosystems and species in the region. For example, a shift in rainfall pattern could impact adversely on the firs and Karoo in southern Africa

by changing the fire regime necessary for re-growth. Reducing run-off could affect marshy ecological units, such as the Okavango Delta and the Surd area.

Impact on Energy

Drought impacts negatively on hydropower potential for electricity generation as a consequence of siltation of dams and river courses. In Ghana, in the first half of 2007, the water level in the Akosombo Dam fell below the minimum level, leading to a reduction in power generation. A reduction of energy also occurred due to the slow growth rate of trees used as a source of fuel wood along the river banks once these had been affected by drought.

The rural areas and the urban poor suffer more from a decrease in energy resources because they have limited alternative sources of livelihood.

Impact on Migration

Drought is a major contributing factor to rural migration to urban centres or to other countries, in search of alternative livelihoods. In Mali, nearly half of the male population has migrated to neighbouring African countries or Europe in search of alternative livelihoods due to drought in their own country. In Burkina Faso, desertification is the cause of 60 per cent of migration to the main urban centres while in Kenya there is a constant flow of the population from rural areas to the capital city.¹⁶ Migration will affect public infrastructure in urban centres and may exacerbate conflict due to scarcity of grazing land and water.

Of all natural hazards, drought is the most damaging. The impacts are due to the vulnerability of communities affected. Drought adversely affects socio-economic and ecological factors and the community's ability to cope with the associated hazard. Policy development related to national and regional management of drought is lacking in most countries. Likewise, drought monitoring, prediction, risk assessment and communication are not conducted effectively in most countries.

Drought has far-reaching effects on the livelihood of affected communities; for example, drought may lead to hunger, disease and even war. It can also have serious health, socio-economic and political impacts, with far-reaching consequences that may include those outlined below.

Impact on Disease

Drought means that no water is provided for essential services such as clean water to drink and water for sanitation and personal hygiene. This predisposes the affected people to a wide range of life-threatening diseases, such as cholera.

Impact on Social Conflict and War

When water is in short supply as a result of drought, the phenomenon creates competition due to a lack of food and people then fight for survival.

Impact on Thirst

Biological entities require water to survive. People can only live for a few days without water and for a few weeks without food.

Kenyan Case Study

A case study on Kenyan droughts has shown that, for many years, the nation has been adversely affected by drought and the situation has not improved. For example, economic growth has fluctuated, which has resulted in lower living standards, with the population largely remaining poor and vulnerable to disasters. Drought has affected economic development, effectively reducing the human development indices in the affected areas. The arid and semi-arid lands, constituting about 83 per cent of the Kenyan land mass, are most affected. About 30 per cent of the country's population and 50 per cent of livestock come from these areas. Arid to semi-arid areas have fragile ecosystems and an unfavourable climate, are historically marginalised and have poor infrastructure, which poses a major development challenge. Drought is the most frequent natural hazard in Kenya, distressing mainly the NorthEastern areas, parts of the Rift Valley, and the eastern and coastal provinces.

Drought Monitoring and Prediction

Drought monitoring and forecasting techniques use advanced satellite imagery and high-resolution spatial data to assess agricultural risks on a regional and local scale. Drought early warning systems are the least-developed systems due to the complex processes and environmental and social impacts of droughts. Droughts have cumulative effects and these may linger for years after the end of the drought event.

Because of these unique characteristics, different approaches are required for reducing the impact of drought. The mechanism of destruction of drought can be considered to be the consequences of its major impact; for example, lack of water from rainfall in the form of soil moisture and lack of water for industrial and domestic consumption. Lack of water from rainfall in the form of soil moisture affects the growth and health of crops and trees. It also affects the health of livestock and humans. In addition, land is subjected to erosion and flooding, especially in areas with no prior conservation measures. These effects are gradual but, if not checked, cause crops, trees and livestock to die and people to lose their livelihoods.

The UN Food and Agriculture Organization Global Information and Early Warning System (FAO-GIEWS) provides information on countries that face food insecurity through monthly briefing reports on crop prospects and the food situation, including drought information, together with an interactive map of countries in crisis. The GIEWS collects drought-status information from several sources, including the FAO-GIEWS, the UN World Food Programme (WFP) and the Famine Early Warning System

(FEWS Net). It packages this information into short notes and a map, which are then provided, on a monthly basis, through the Humanitarian Early Warning Service (HEWS) website. Benfield Hazard Research Centre uses various data to produce a monthly map of current drought conditions; these maps are accompanied by a short explanation regarding each country.

On a regional scale, the FEWS Net for East Africa, Afghanistan and Central America reports on current famine conditions, which include drought, by providing monthly bulletins that are accessible from the FEWS Net webpage. In the US, the US Drought Monitor¹⁷ provides current conditions regarding drought at national and state levels through an interactive map that is available on the website; a narrative on current drought impacts and brief forecasts for the following week are also provided. The US Drought Monitor, which is a joint effort of the US Department of Agriculture (USDA), NOAA, Climate Prediction Centre, University of Nebraska Lincoln and others, has a unique approach that integrates multiple drought indicators with field information. It has become the best available product for drought information.¹⁸

In China, the Beijing Climate Centre (BCC) of the China Meteorological Administration (CMA) monitors drought development. Based on a precipitation and soil moisture monitoring network and remote-sensing-based monitoring, CMA's National Satellite Meteorological Centre prepares a drought report and a map on current drought conditions daily. The European Commission Joint Research Centre (EC-JRC) provides publicly available drought-relevant information through the following real-time online maps: daily soil moisture maps of Europe; daily soil moisture anomaly maps of Europe; and daily maps of the forecasted topsoil moisture development in Europe (seven-day trend). In addition, the World Meteorological Organization (WMO) provides useful global meteorological information, such as precipitation levels, cloudiness and weather forecasts, which is presented visually on a clickable map on the WMO website.

Drought Comparison

Droughts differ from other natural hazards in important ways. Drought is a slow-onset hazard; it starts slowly and its exact beginning and ending cannot be pinpointed. In some cases, the start and end of a drought can only be estimated in retrospect, as people, economies and environments recover from their consequences. This is in contrast to sudden-onset hazards such as floods, earthquakes, volcanic eruptions and industrial accidents, as the effects of these hazards are immediate and tend to become disastrous quickly.

Conclusion

Existing approaches to drought early warning must be improved. Owing to the complex nature of drought, a comprehensive and integrated approach (such as the one adopted by the US Drought Monitor), which would consider numerous drought indicators, is required for drought monitoring and early warning. Although all types of droughts originate from a precipitation deficiency, monitoring only this parameter is insufficient for assessing a drought's severity and resultant impact. Precipitation must be integrated with other climatic parameters and with water information such as stream flow, snow pack (wherever applicable), groundwater levels, reservoir and lake levels, and soil moisture into a comprehensive assessment of current and future drought and water-supply conditions. In addition, for large parts of the world that suffer from severe drought, early warning systems are not yet in place, such as in western and southern Africa and also in eastern Africa, where FEWS Net is available but no drought forecast is provided. Parts of Europe (Spain, parts of France, southern Sweden and northern Poland) are characterised by high drought risk, but have no drought warning system in place. India, part of Thailand, Turkey, Iran, Iraq, eastern China, areas of Ecuador, Colombia, and the southeastern and western parts of Australia also require drought warning systems.

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CHAPTER 9

Saharan Dust

A Scientific Review

Abdourahamane Konaré, Siélé Silué and N'datchoh E. Touré

Introduction

In atmospheric studies, aerosol is rarely considered as an entity but rather as aerosol population, which is an ensemble of aerosols. Within this aerosol population, particles have variable sizes and morphologies. The desert aerosol, also known as 'mineral dust' or, simply, 'dust', is part of the family of atmospheric trace species.

Desert areas are the main sources of atmospheric mineral dust. Worldwide, global modelling studies estimate a dust emission of 11 000 to – 5 000 Tg per year.¹ However, numerous uncertainties surround these estimates. According to these models estimates, around 40-70 per cent of global dust emission is from the North African deserts. Mineral dust most active sources are mainly located over sub-tropical latitudes, where the water availability is limited (especially the western parts of the continent). Also, vegetation cover is sparse and this gives the impression of a dust belt. As water is one of the main limiting factors for vegetation, the arid and hyper-arid climate of desert areas is commonly classified by the ratio of the mean annual precipitation and the mean annual evapotranspiration. Around 7.5 per cent of the world's total land surface is classified as hyper-arid areas; around 12 per cent is classified as arid areas.²

The Sahara Desert is recognised as the strongest primary dust source worldwide followed by the Chilean-Peruvian Desert.^{3,4} The term 'primary' refers to dust directly produced from the ground by farming, mining or wind action over arid and semi-arid areas of the globe.

Mineral dust is the main component of the tropospheric aerosol. Dust contributes to more than one third of the annual atmospheric aerosols at global scale.^{5,6} However, these estimates are also uncertain.

The desert dust cycle contributes to soil impoverishment over sources regions throughout the emission processes and to enrichment of ocean and/or continental surfaces via deposition processes after transportation away from sources. Moreover, dust events may lead to the worsening of weather conditions and may negatively

affect socio-economic elements such as air traffic, ground transportation⁷ and population health. Many studies on desert aerosols are focused on their radiative impacts and thus their climatic implications.^{8,9}

The most intense dust events in the Sahara and Sahel regions are frequently generated in summer¹⁰ due to favourable large-scale conditions (surface pressure and surface temperature anomalies over the ocean), but significant dust production also occurs throughout the year.

In addition, the wide spread of biomass burning during dry seasons makes Africa one of the strongest sources of biomass burning aerosols in the world.

The increasing occurrence of diseases such as asthma, infections, meningitis¹¹ and valley fever seems to be related to dust outbreaks. Daily aerosol samples collected in trade winds at Barbados, West Indies, throughout 1996–1997, showed that mineral dust often contain viable fungi and bacteria, which may cause allergic reactions or asthma.¹² Furthermore, dust in general impact on air quality which is an emerging issue for governments.¹³

Emissions, Source Areas and Transportation

Globally, North Africa is the main source area: of atmospheric mineral dust; it contributes approximately 50 per cent of world production, which is estimated to be 1 000 to 2 000 Mt/year.¹⁴ The first consequence of the wind activity in the Sahara and Sahel regions is the movement of large quantities of sand and dust. The dust cycle is driven by a set of mechanisms related to environmental, climatic and meteorological conditions prevalent in North Africa. This cycle is characterised by particle uplift from well-known sources, atmospheric large-scale transport that can extend far beyond the Sahara and Sahel and particle deposit. For example, every year, large amounts of Saharan aerosol are transported from North Africa and the Chad Basin to the Gulf of Guinea, by the north-east winds.

It is recognised that some of these mineral aerosol emissions have an anthropogenic origin. Human through their agricultural and grazing activities may lead to expose previously vegetated land to becoming potential emission source under wind erosion. That is the case for example the southern Tunisia¹⁵ and Gao.^{16,17}

Various studies have been conducted in an attempt to quantify the anthropogenic emissions of desert aerosols. For example, Sokolik and Toon suggested that they represent only 20–30 per cent of mineral aerosols.¹⁸ Even if estimates are lowered,^{19,20} much uncertainty persists regarding the quantification of anthropogenic aerosol emissions.

Mineral Dust Formation Process

The desert aerosols are a product of the mechanical action of wind on the soil. Weather conditions (strong winds, low rainfall) and soil type are the two main factors involved in dust mobilisation. Wind erosion results in partial or total removal of soil particles, mainly through deflation and abrasion. Deflation is the direct removal of loose particles of soil by wind. It acts on soft substrates, such as granular soils, alluvial deposits while abrasion involves the removal of soil particles from aggregates and/or crusty soils. Saltation consists in particle mobilisation by hitting these aggregates and crusts (sandblasting), which releases other particles that, in turn, move.^{21, 22} Vegetation cover and soil moisture are almost the only obstacles to mineral dust mobilisation. The aerosol emission process controls not only the amount of transportable aerosol but also the characteristics of the particles, including their size (Figure 9.1). Once mobilised, the particles move depending on their size, by saltation, sandblasting or suspension. The processes of saltation and sandblasting occur only when the threshold speed of soil erosion is exceeded. The saltation process ejects grain sizes of between about 50 and 1 000 microns from the soil surface.

In the saltation process successive jumps occur one after the other, with ballistic trajectories in the direction of the airflow. The height reached by the grains defines the saltation layer. It (height) varies from a few centimetres to a meter and depends on the balance between kinetic energy and the potential energy of grains in movement. Particles smaller than about 50 microns, most often produced by sandblasting, are generally mobilised when their suspended movement allows them to exceed the maximum height of the saltation layer.²³ These fine particles make up mineral aerosols that are transported from the source areas over long distances. In summary, the uplifting of dust particles in source areas occurs when the following conditions are met:

- No obstacle (vegetation, humidity) on the surface prevents the mobilisation of particles;

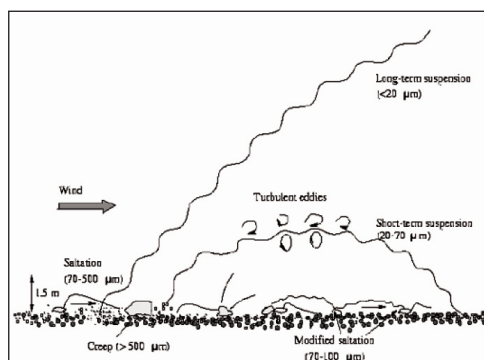


Figure 9.1: Movement of grains of soil in response to wind and depending on their size.²⁴

- Particles (generated by wind, water erosion or thermal action) that can be mobilised by the wind are present in large quantities in the soil; and
- Energy input from the wind at the surface is sufficient to overcome the forces of inter-particle cohesion.

Main Source Areas

Most desert aerosols are emitted from arid and semi-arid zones. The surfaces in these zones are the least protected from erosion by the very weak (or non-existent) vegetation cover and a very small soil moisture effect, which limit the cohesion of the soil components. 'Aridity' refers to a situation of permanent lack of water resources in the air and soil and therefore depends on climatic parameters and the type of soil. Aridity differs from the drought, which is caused by an adverse time-limited atmospheric situation. In general, the amount and seasonal distribution of rainfall delineate different semi-arid and arid areas. Arid and semi-arid areas are generally located on either side of the equator, in the sub-tropical anti-cyclone belt. The main desert aerosol sources of the Sahara- Sahel region are located nearby mountainous regions. This is the result of two main factors: the presence of abundant sediment in these areas, due to water erosion, and the frequent occurrence of strong surface wind, which is associated with the presence of low level jets (LLJ). The frequency and intensity of surface wind are enhanced by orography, based on the following conditions:²⁵

- Soils are rich in fine particles this condition leads to a geographical location; and
- Conditions ensure the mobilisation of the dust and its transfer to a sufficient altitude.

Brooks and Legrand²⁶ located four main source areas of dust in North Africa from the Infrared Difference Dust Index (IDDI) from METEOSAT infrared (IR) imager: Bilma ergin Tchad; the ergs Iguidi and Chech, which lie north of Mauritania and Mali and southern Algeria; and an area in northern Sudan and southern Egypt; and the fourth in northern Niger and southern Libya (Figure 9.2). More recently, the Engelstaedter et al.²⁷ study, which is based on the Total Ozone Mapping Spectrometer (TOMS) Aerosol Index, traced the configuration of source areas in North Africa in four main areas: the Bodélé Depression in Chad West Africa, covering wide areas of Mauritania, Mali and southern Algeria; the Nubian Desert; and the Libyan Desert (Figure 9.3).

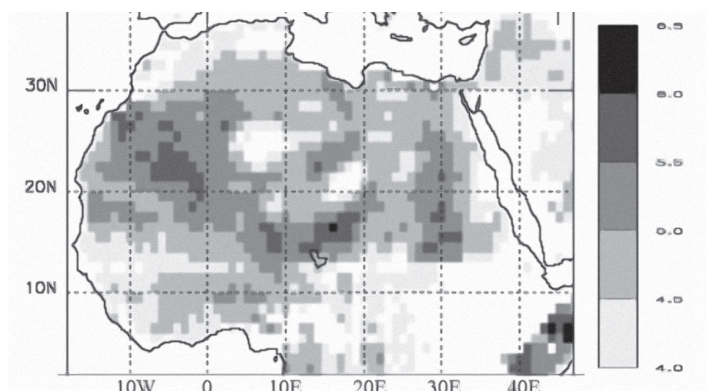


Figure 9.2: Annual METEOSAT-IR IDD average in Kelvin over the period 1984-1993, indicating the locations of the main source areas of desert aerosols in North Africa.²⁸

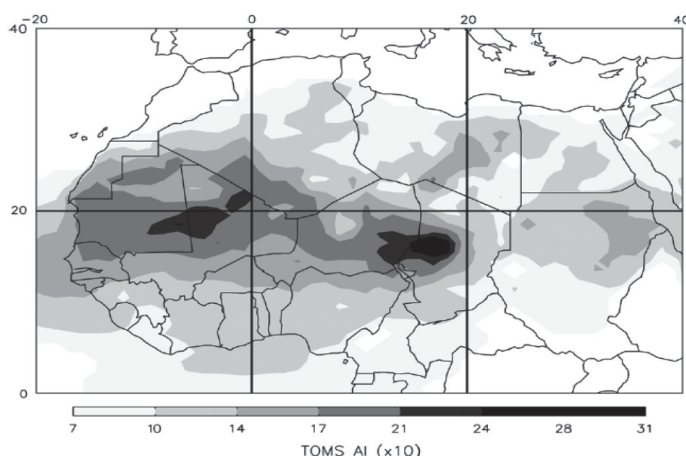


Figure 9.3: Monthly average of the TOMS AI (10) for the period 1980-1992, showing the main source areas in North Africa: Bodélé depression; West Africa; Nubian Desert; and Libyan Desert.²⁹

On the basis of the reduction of horizontal visibility, Bertrand³⁰ identified two main source areas: the first is located in northern Niger and Chad and covers the basin of Chad and the Ténéré; the second source is in Mauritania.

In addition, more recent studies have shown that dust sources in North Africa vary during the year, with changes in the weather.³¹ New source regions and changes in existing sources appear as consequences of anthropogenic activities and atmospheric dynamics as illustrated in Figure 9.4, Gao and Mopti^{32,33} (high 'valley' of Niger), for example, indicate human impacts. The activity of Bodélé Depression in Chad which is strongly dependent on the presence and strong LLJs, is an example of the effect of atmospheric dynamics.^{34,35}

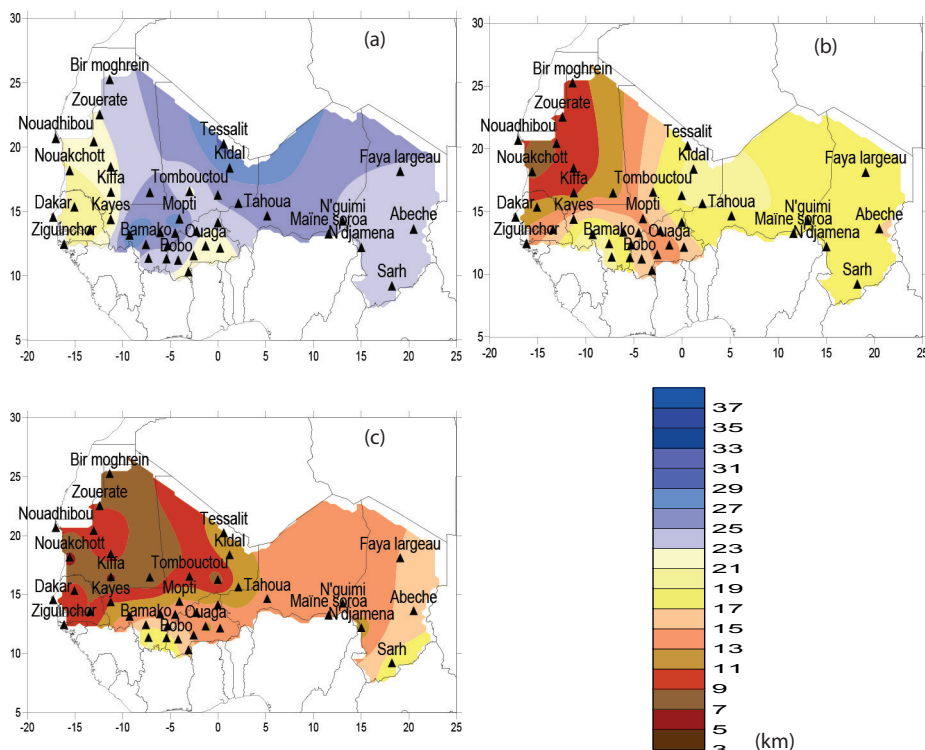


Figure 9.4: Comparison of the evolutions of mean horizontal visibility for the periods: (a) 1957-1961; (b) 1970-1974; (c) 1983-1987.³⁹

Saharan Dust Transportation

Dust transportation is strongly influenced by meteorological and weather conditions prevalent at the sources and surrounding regions, which determine characteristics such as direction, speed, trajectory, altitude, distance and duration of transportation. Particles do not go far in unfavourable conditions that do not prolong their flight at higher altitudes and over greater distances. If conditions are unfavourable, the dust remains in the immediate vicinity of the source area; if they are favourable, by advection movement, the particles leave the lower layers of the atmosphere and rise in altitude (2–4 km). They are dispersed and transported over long distances, travelling in the free troposphere. Dust has been observed to be transported over long distances. The length of travel is inversely proportional to particle size. North Africa as the strongest source area makes the largest contributions to the global atmospheric dust quantities. Saharan dust is transported over the Atlantic Ocean^{36,37,38} towards the Mediterranean Sea^{40,41} and the far East.^{42,43} Frequently, dust is transported towards southern Europe⁴⁴ and farther north towards central and north Europe⁴⁵. Besides dust transportation towards the Atlantic, Mediterranean and Red Sea regions, an inter-hemispheric transport of Saharan dust is also documented in the literature.

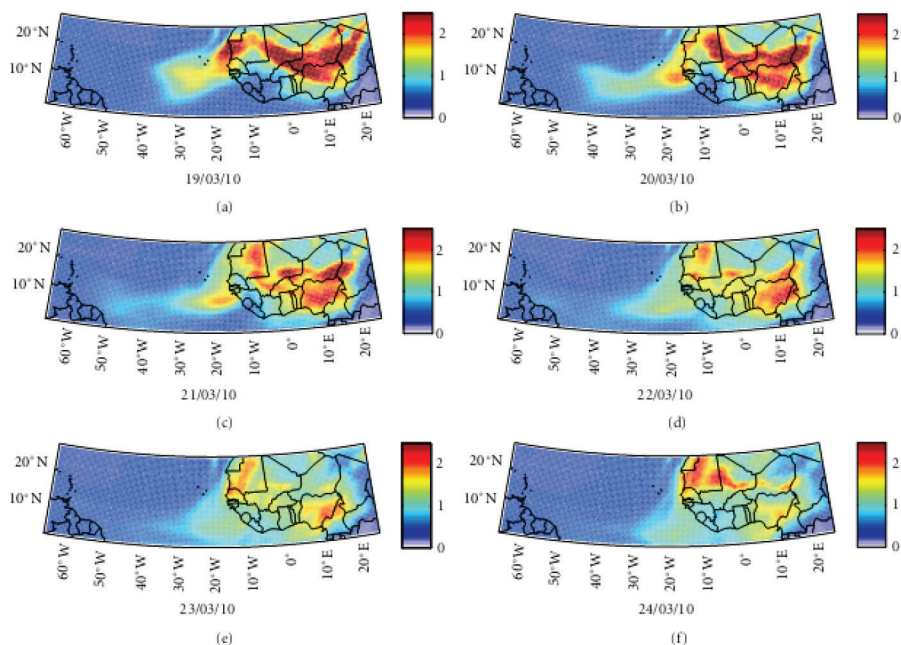


Figure 9.5: Drift of dust particles from the African continent over the Atlantic Ocean - simulated with RegCM 4.0 between 19 March and 24 March 2010.⁵⁴

Koren et al.⁴⁶ describe how Saharan dust is transported towards the Amazonian rain forest and the Andes.

Dust plumes from North Africa have three main trajectories (Figure 9.5):

- Transatlantic transportation to the Gulf of Guinea, the United States, the Caribbean and South America;^{47,48}
- Transportation to the Mediterranean and Europe;^{49,50} and
- Transportation to the Near East and the Middle East.⁵¹

Transcontinental transportation of aerosol plumes from North Africa to Japan (across the Middle East and Southeast Asia) has also been suggested Tanaka et al.⁵² More recently, Touré et al.⁵³ showed that a dust plume from Chad and northern Niger took between three and five days to reach the Atlantic Ocean (Figure 9.5).

Impact of Mineral Dust

Interest in the properties of small airborne aerosols has increased because of the role that they play in many environmental processes. Much of this interest stems from the possible impact of aerosols on climate-related processes that involve radiation and clouds. For this reason, aerosol studies have focused on the chemical and physical properties of aerosols that relate to radiation and to hygroscopic behaviour.

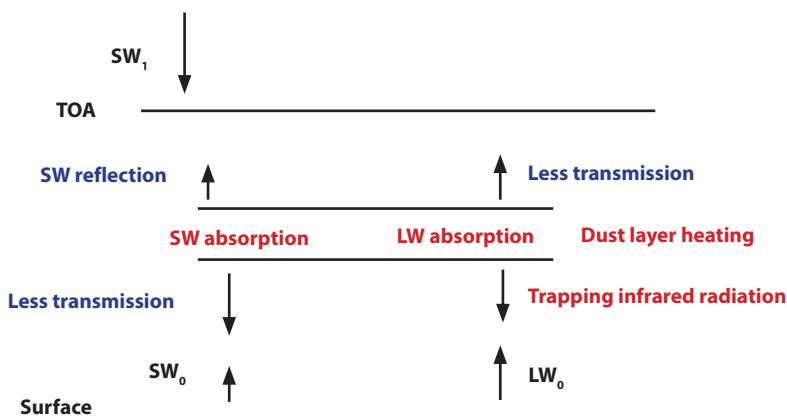


Figure 9.6: Schematic illustration of interaction of mineral dust aerosols with radiative components of the atmosphere during daytime. Daytime surface cooling is caused by shortwave (SW) reflection dominating over longwave (LW) trapping induced by dust aerosols.⁵⁹

Radiative impact

Airborne dust can influence the climate by altering the radiative properties of the atmosphere, but the magnitude of the effect is uncertain.⁵⁵ Airborne dust both reflects and absorbs solar radiation. It also absorbs and emits IR radiation, thus contributing to the green-house effect. However, the current net direct radiative effect of dust is unclear, because there is still much uncertainties exist regarding present-day atmospheric distribution and optical properties of dust. For example, Myhre and Stordal⁵⁶ conclude that the range of globally averaged top-of-atmosphere (TOA) forcing lies between -1.4 and $+1.0 \text{ W.m}^{-2}$. Furthermore, the effect that dust will have on the future climate is unknown, since uncertainties still exist in estimates of magnitude and sign of future changes induce atmospheric dust loading.^{57,58} Figure 9.6 provides a schematic illustration of the impact of dust on solar radiation.

The TOA forcing depends on the surface albedo and properties of the atmospheric column and on the dust optical properties. Locally, the TOA effect can be either positive or negative.⁶⁰ Over dark surfaces (e.g. ocean) because dust increases the apparent reflectance of the Earth. This induced SW reduction is usually associated with LW increasing, resulting in a net cooling of the column. Over bright surfaces, such as snow or desert, or cloud-covered surfaces, absorption of solar radiation dominates over scattering, causing a net TOA warming, unless the reflectivity of dust is very high.⁶¹ Global calculations indicate that the (positive) LW and (negative) SW forcing tend to equilibrium, so that the globally averaged TOA forcing is close to zero.⁶² However, the sign of this global mean forcing is strongly dependent on the specific optical properties of the dust.⁶³

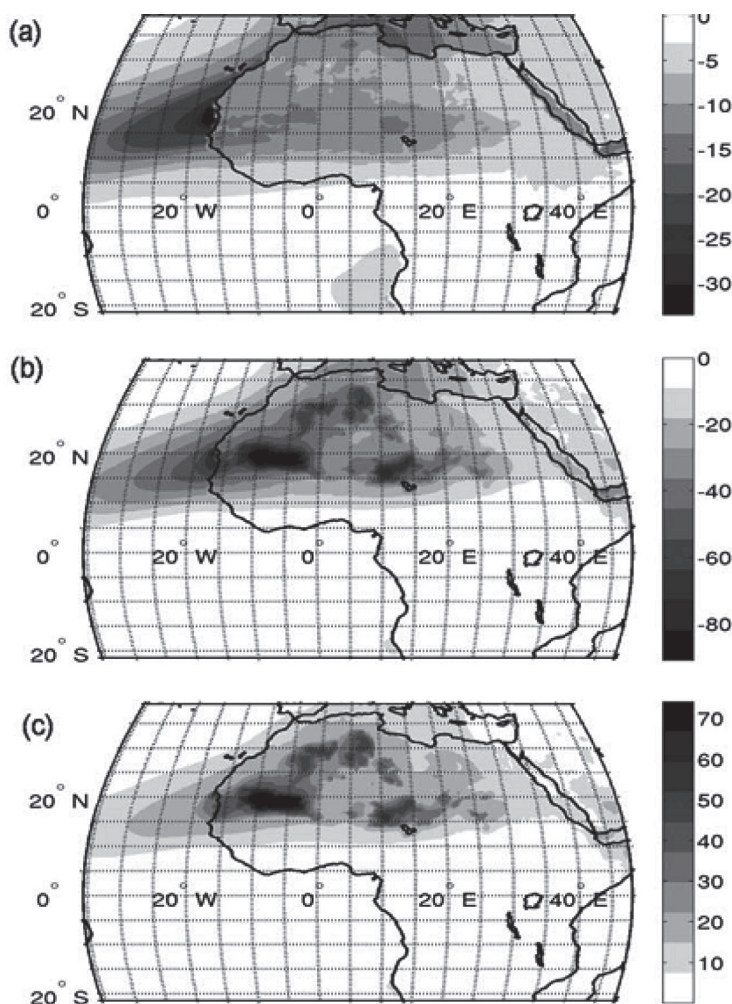


Figure 9.7: Simulation of dust SW radiative forcing in W.M-2 (JJAS, 1969-2006). (a) Top of atmosphere (TOA). (b) Surface (SRF); and (c) Absorption in the atmosphere (TOA-SRF).⁶⁴

Figure 9.7 shows the TOA and surface clear sky SW dust radiation forcing. The TOA forcing is negative (Figure 9.7a), which implies a general cooling of the surface/atmosphere system induced by the dust load and the associated high single scattering albedo. Because of the low albedo of water, the TOA SW radiative forcing is more effective over the eastern Atlantic and reaches -30 W.m^{-2} , with an optical depth of as high as 1, close to the Mauritania coast. The SW surface radiative forcing (Figure 9.7b) varies from 0 to -90 W.m^{-2} over areas of maximum dust loading. The difference between surface and TOA forcing is proportional to the SW diabatic heating of the atmosphere, due to the absorptive component of the dust (Figure 9.7c).

Even though the TOA forcing is often small, the surface forcing can be relatively large. Both solar absorption and reflection within the atmosphere tend to cool

the surface, allowing less solar radiation to reach the surface. While an increased LW flux (due to the dust green-house effect) somewhat balances the cooling, the net result is normally large and negative. Since the direct radiative effect of dust varies temporally and spatially and is thus difficult to measure, the globally averaged effect has been explored using radiative transfer models with specified dust distributions.^{65,66,67} The results seen in previous modelling work undertaken on dust forcing and climate response are summarised in Table 9.1 and show both positive and negative net TOA forcing.

Table 9.1: Annual and global average SW, LW and net dust forcing radiative transfer model results (given in W.m^{-2})⁶⁸

Model	TOA SW	TOA LW	TOA Net	Surface SW	Surface LW	Surface Net
Tegen et al. ⁶⁹			+0.14			
Miller and Tegen ⁷⁰			-0.1			-2.1
Woodward ⁷¹	-0.16	0.23	0.07	-1.22	0.40	-0.82
Myhre and Stondal ⁷² 1	-0.02	0.41	0.39			
Myhre and Stondal ⁷³ 2	-0.53	0.13	-0.40			
Jacobson ⁷⁴			-0.14			-0.85
Perlwitz et al. ⁷⁵	-0.5	0.1	-0.4	-2.1	0.40	-1.7
Claquin et al. ⁷⁶			-1.2			
Miller et al. ⁷⁷	-0.33	0.15	-0.18	-1.82	0.18	-1.64
Miller et al. ⁷⁸ ($0.9 \times \omega$)	0.61	0.15	0.76	-2.65	0.18	-2.47
Miller et al. ⁷⁹ ($1.1 \times \omega$)	-0.96	0.14	-0.82	-1.24	0.17	-1.07
Miller et al. ⁸⁰			-0.39			-0.82
Yoshioka et al. ⁸¹	-0.92	0.31	-0.60	-1.59	1.13	-0.46
Shell and Somerville ⁸² ($\omega = 0.97$)	0.73	0.23	-0.49	-1.34	0.37	-0.97
Shell and Somerville ⁸³ ($\omega = 0.85$)	-0.31	0.23	-0.07	-2.70	0.37	-2.33

Forcing given in W/m^2 . Myhre and Stondal⁸⁴ used two different dust distribution models: (1) Koepke et al.⁸⁵ and (2) Tegen and Fung.⁸⁶ Results from this work are shown for two different SW single scattering albedos. The LW forcing for these two cases is identical.

The heating changes can, in turn, cause dynamic changes in atmospheric circulation and stability. Increased absorption of solar radiation within the atmosphere results in atmospheric warming and surface cooling.⁸⁷ This redistribution of heating within the column affects the stability of the atmosphere, with implications for convection, latent heat transportation, cloud coverage and precipitation.

Impact on precipitation

Over Africa, two phenomena play a dominant role in the local weather and climate conditions. First, the monsoon is the driving mechanism of the climate on the continent,

and therefore plays an important role in the social and economic development of the people living in the tropics. Second, dust storms from the dry areas have a profound impact on weather conditions and the lives of the local people. The Saharan dust emitted during the West African Monsoon (WAM) season can significantly affect the WAM development and precipitation, because it interacts with both SW and LW radiation, and modifies the radiative and physical properties of clouds.^{88,89,90} These studies^{91,92,93} used general circulation models (GCMs) and have provided important information to help understand the fundamental processes associated with the effect of dust on precipitation during the WAM season.

The decrease in rainfall and the devastating droughts in the Sahel region during the last three decades of the twentieth Century are among the largest recent climate changes that are recognised by the climate research community.⁹⁴ The large temporal and spatial coherence of the dry (and wet) conditions is the exceptional characteristics of rainfall variability in the Sahel.⁹⁵ A number of studies have investigated the possible causes or mechanisms of the Sahel drought in the last 30 years. Some authors, such as Prospero and Lamb⁹⁶ hypothesise that dust plays a role in the change in the Sahel climate. They note that dust radiative forcing is important in this region and that it can modulate the inter-hemispheric sea surface temperature (SST) gradient, which may be responsible for precipitation variability in the Sahel.

Miller et al.⁹⁷ found that precipitation may be enhanced locally over the Sahel in response to the radiative forcing of dust; while Yoshioka et al.⁹⁸ showed that rainfall is reduced over the Sahel due to weakly absorbing dust and estimated that ~30 per cent of the reduction in precipitation observed in the Sahel from the 1950s to 1980s may be attributed to dust. Kim et al.⁹⁹ showed that dust radiative effects may strengthen the WAM, which is characterised by a northward shift of the West Africa precipitation over land. Konare et al.¹⁰⁰ and Solomon et al.¹⁰¹ used a regional climate model to show that the WAM precipitation response to dust radiative forcing is highly sensitive to the absorption properties of dust.

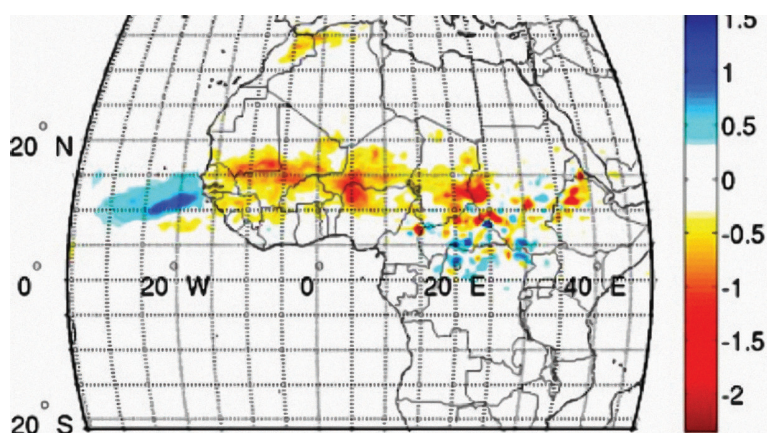


Figure 9.8: Precipitation change (in mm.d⁻¹) due to the radiative effects of dust.¹⁰²

Figure 9.8 shows the average impact of dust radiative forcing on Sahel precipitation. This is a result of positive feedback related to dust radiative forcing in the maintenance of dry periods over western Africa. We also note that the effects of dust on precipitation and monsoon dynamics produce anomaly patterns similar to those found during dry years over the Sahel, which suggests positive feedback related to dust radiative forcing in the maintenance of dry periods over western Africa.

Some authors^{103,104} studied the inter-annual variability of mineral dust and the correlation between the Sahelian drought and dust concentrations. All these studies found a negative correlation between mineral dust and rainfall in the Sahel. N'Tchayi et al.¹⁰⁵ and Silue et al.¹⁰⁶ showed that significant increases in dust emissions appear as a result of drought conditions which were prevalent in the years 1970-1980 in the Sahel.

Socio-economic impact

The impact of mineral dust on climate, ecosystems and air quality (and consequently on economic and human health) presents a major and societal challenge. Transportation of soil dust has a number of implications for humans. The generation and transportation of dust are processes that continue to this day and that play an important role in geochemical and geophysical processes, including the addition of nutrients to soils and to the oceans. Aerosol properties have attracted renewed interest because of evidence that exposure of humans to high concentrations of airborne particulate matter (PM) can have a detrimental effect on their health. Much evidence is based on epidemiological studies of death rates and respiratory-related hospital admissions (e.g. aggravated asthma, severe respiratory symptoms and chronic bronchitis). Regions that have higher concentrations of particles tend to have higher rates of admissions than those with lower mean levels. Short-term exposure also appears to have an impact, as reflected in sharply increased admission figures during severe pollution episodes.

More recently, there has been a new focus on the effects of aerosols on human health. The United States Environmental Protection Agency or EPA standard for suspended PM focuses on particles with a diameter of 10 μm or smaller. In July 1997, the EPA established a new standard for particles of 2.5 μm in diameter or smaller.¹⁰⁷ EPA's new PM_{2.5} standard specifies an annual mean of 15 $\mu\text{g}\cdot\text{m}^{-3}$ and a 24 hour mean of 65 $\mu\text{g}\cdot\text{m}^{-3}$. Only these small particles can efficiently enter the lungs. It has long been known that, in certain industrial environments (e.g. mines and factories), clearly identifiable health effects are associated with specific minerals (e.g. silica and asbestos). However, a substantial fraction of windborne soil dust is found in this 'respirable' size range. Thus, we must consider the possible impact of ambient mineral dust on human health. For example, strong inhalation of airborne dust causes an allergic reaction that is manifested in ocular secretions, respiratory infections, cardiovascular diseases and many other disorders.¹⁰⁸

A large number of epidemiological investigations have demonstrated that atmospheric PM pollution causes morbidity and premature mortality. The long-term exposure to fine PM, with an aerodynamic diameter that is smaller than $2.5\ \mu\text{m}$ ($\text{PM}_{2.5}$), is associated with adverse health impacts, including increased risk of premature mortality due to cardiopulmonary disease and lung cancer.^{109,110,111} Most of the studies that relate air quality to human health have been performed in urban areas, mainly in the US and Europe, where the particulate pollution is dominated by anthropogenic particles. Relatively little work has been carried out on the impact of natural $\text{PM}_{2.5}$ such as mineral dust. In the atmosphere, large amounts of desert dust can travel thousands of kilometres from its source, which represents one of the main natural contributions of airborne PM.^{112,113}

In many regions, the level of $\text{PM}_{2.5}$ far exceeds the World Health Organization (WHO) limit of $10\mu\text{g.m}^{-3}$ and the European Standard on Ambient Air Quality and Cleaner Air for Europe of $20\mu\text{g.m}^{-3}$,¹¹⁴ due to regular dust events. North Africa and the Middle East are the main dust sources (over 60 per cent of the global dust load), and therefore the potential risk to health is higher for populations in these regions. South and East Asia, with high population densities, are also affected by severe dust events. Unfortunately, in these parts of the world, epidemiological studies and adequate air quality data are largely lacking. Several studies mention adverse health effects on the cardiorespiratory system that are associated with dust, but very few present quantitative results.^{115,116}

Conclusion

Dust generation is a highly non-linear process that is extremely sensitive to climate change. Indeed, the geological record shows that dust mobilisation has varied tremendously over time. Recent research suggests that mineral dust also plays a significant role in climate forcing. Thus, there could be feedback between the climate-dust generation processes and the climate-forcing effects of mobilised dust.

The presence of high concentrations of mineral dust over large areas of the Earth has implications for many areas of science, such as meteorology, climate and biogeochemical processes. To assess the role of dust in these processes, we need a better understanding of the properties of the airborne soil particles.

Finally, there is a renewed interest in the health effects of fine particles, as reflected in the new EPA regulations regarding suspended particles of $< 2.5\ \mu\text{m}$ in diameter. In many regions of the world, mineral dust is the dominant aerosol constituent and, consequently, dust could constitute a widespread health threat.

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CHAPTER 10

Occurrence and Effects of Climate Change in Sub-Saharan Africa

Ellis Mbaka Njoka

Introduction

The term 'climate' refers to average weather over a 30-year period. The climate system is complex, with various influencing and interacting factors, the Earth's surface, snow and ice, oceans and living organisms. The global mean temperature increased by 0.6 degrees Centigrade in the last century, with the hottest years ever on record occurring after 1990. This warming of the world's climate has been linked to a higher concentration of greenhouse gases (GHGs) in the atmosphere, the consequences of which can be seen in the higher frequency of extreme events such as floods, droughts and cyclones. The Sahel region has had its fair share of changes. While rainfall variability is a major characteristic of the Sahelian climate, the second half of the twentieth Century witnessed a dramatic reduction in mean annual rainfall throughout the region.^{1,2,3,4,5} According to the Intergovernmental Panel on Climate Change (IPCC), a rainfall decrease of 29-49 per cent was observed in the Sahel region in the 1968-1997 period, compared to the 1931-1960 baseline period.⁶ All of this evidence has led the scientific community to agree that global climate change is a reality.

Convincing evidence from sub-Saharan Africa indicates that climate change is a reality. In Senegal, for example, an earlier cessation of summer rains took place over a period of 43 years between 1950 and 1992.⁷ Average cessation dates shifted from 9 October in the period 1950-1992 to 25 September in the years 1970-1992. Similar studies conducted in northern Benin and Cape Verde showed a decreasing trend in the duration of the wet season.⁸ Stable onset and cessation dates were observed in the periods 1959-1978 and 1979-1998.⁹ In Mali, a detailed analysis of rainfall data provided similar conclusions regarding the mean annual rainfall in 1970, which was 30 per cent lower than usual.¹⁰

It is suggested that humans will experience more climate change in the next 100 years than they have in the last 10 000 years.¹¹ The main contributor to climate change is GHGs.¹² Climate models and historical data indicate a doubling of carbon

dioxide (CO₂), elevated global mean surface temperature, evaporation and precipitation, a small rise in sea levels and other uncertain effects.¹³ The growing concern and agreement on the causes and effects of climate change resulted in a collaborative endeavour internationally. It is in line with this endeavour that, in 1997, world leaders gathered in Kyoto to consider a protocol on restrictions on the emission of GHGs that increase the earth's atmospheric and surface temperatures.¹⁴

With climate change, drought and floods are predicted to surge in frequency and intensity, especially in dry lands. However, data limitations mean that temporal and spatial uncertainties persist regarding the nature of climate changes. How such changes will influence the frequency and intensity of extreme climate events is uncertain. While ongoing efforts to improve the climate database and quality of climate projections may provide better projections, a resilient approach that focuses on enhancing adaptive capacity for dealing with change and uncertainty holds potential for identifying options for adaptation to weather vagaries.

The responsibility of the United Nation's Framework Convention on Climate Change (UNFCCC) is to maintain GHG concentrations at levels that would discourage hazardous anthropogenic interference with global climate. Historical climate data paints a gloomy picture, with the African continent already undergoing climate change.¹⁵ The Kyoto meeting noted that Africa is severely affected by climate change due to low development, widespread poverty, droughts, inequality in land distribution, low per-capita gross domestic production, limited ability to adapt financially and institutionally, and reliance on a rain-fed agricultural sector.

Definitions

Climate change is the state of the climate as identified by use of statistical tests, and by changes in the mean and/or the variability of its properties, which persists for a lengthy period of time, normally decades or longer.¹⁶ Climate change may be caused by natural forces or continuous anthropogenic fluctuation in the configuration of the atmosphere and in land use.¹⁷ Generally, this is a process of global warming, to some extent attributable to GHGs, due to anthropogenic activities.

Climate is a global unrestricted good as no one can be barred from the services it offers. There is also no competition in consumption as multiple users in different places in the world simultaneously consume its services. This means that negative and positive externalities can accrue from the same. For example, GHG emissions of individuals or countries can have positive and negative effects on other individuals, places and countries. The fact that there is no functioning market for climate services means that no one is willing to pay. This creates the problem of free riders; that is, individuals, firms and countries that emit GHGs at the expense of others (tragedy of commons). Hence, the role of the UNFCCC is particularly necessary.

Effects of Climate Change

Effect on crops

Climate change has a great impact on the production of cereal crops, such as sorghum (*Sorghum bicolor*), which is characteristically grown in the semi-arid tropics (SAT). These regions are characterised by high temperatures, high evaporation, variable rainfall and poorly structured soil that has a low water-holding capacity and low fertility. These qualities adversely impact the physiological processes of plants. Sorghum production is affected by several abiotic constraints, including water constraints. Water will likely be the primary yield constraint in the SAT in the future.¹⁸ Most of the reduction in cereal crop yield generally is due to water stress.¹⁹ Sorghum is a C₄ plant and therefore better adapted to soil moisture stress than C₃ plants. The rates of transpiration and photosynthesis are greater in C₄ plants than in C₃ plants,²⁰ which means that sorghum uses water more efficiently. This advantage translates into greater plant or crop water use efficiency.

Impact on the environment

Some sunlight is reflected and some absorbed while a number of transparent gases in the atmosphere absorb infrared radiation from sunlight (in the infrared spectrum), which obstructs outward radiation and thus warms the atmosphere, hence global warming.²¹ The GHG effect is clear enough, with the dispute being its impact over the coming century, its effect on climates around the globe and its impact on human health and the natural surroundings. The understanding of its impact requires a multi-disciplinary approach.²² Future costs of climate change are strongly linked to factors such as population growth, land use changes and increased wealth.

Global warming is becoming a threat to humankind and an estimated 13 million other species.²³ A reduction in biodiversity, due to air pollution and increased ultraviolet radiation, has been noticed globally. Human activities have contributed immensely to global warming through a variety of social variables and conditions such as technological developments, global inequalities in emissions, fuel efficiency, deforestation, demographic trends, political treaties and policies, social structures, ecological debt and operations, and economic systems.^{24,25,26} Planning and preparing for future changes are essential, rather than using uncertainty as a reason for inaction.

Two global warming hypotheses have been posited.²⁷ These are, first, the occurrence of a large atmospheric temperature increase due to GHGs and, second, that this temperature increase leads to rising storm activity and catastrophe world-wide. Flooding and climatological changes have come to be associated with global warming. GHGs in the atmosphere reduce the emission of terrestrial thermal infrared radiation, escalating CO₂, which, in effect, increases radioactive energy input to the Earth.²⁸ The ability to forecast possible changes in CO₂ concentration, using historical

data, is important. Energised Autoregressive Conditional Heteroscedasticity (EARCH), a volatility forecasting model, is suitable for this work in the short- and long term.

The impact of global warming on the environment includes the rapid rise of extreme weather events; significant decline in surface water resources; high rate of desertification in arid and semi-arid areas; increased threat to health – with an increase in malaria incidences; and biodiversity decline.²⁹ A consistent pattern of climate change (between 1960 and 2009) was noted, specifically in terms of rainfall and temperature data.³⁰ A forecast to 2025 predicts that Kenya, for example, will experience over a hundred millimetres less long-seasonal rainfall by that date. Future climate change scenarios for Kenya include a temperature increase, uncertain rainfall projections, and extreme events in the form of floods and droughts.³¹ On the positive side in the process of mitigating climate change effects, Kenya could benefit socially, economically and environmentally through new sources of revenue and employment opportunities, livelihood diversification and biodiversity conservation. Other benefits include increased appreciation and stewardship of forestry; protection of water sources; improvement of water filtration; increased resilience in adapting to climate change; and land restoration and a reduction of soil erosion.³²

Level of GHGs

Levels of CO₂ are expected to rise significantly because of rapid industrialisation and population growth. The consequences of a CO₂ level of 650 ppm include an increase in temperature, erratic weather patterns and slowing ocean currents. Elevated levels of CO₂ were observed in the atmosphere in comparison to previous trends.³³ It was also observed that simulation models are limited as they have few observable variables, although they provide a useful forecast. The general concentration of CO₂ is reported to have increased during the past century.³⁴ Before the Industrial Revolution, the atmospheric CO₂ concentration was about 270-280 ppm.³⁵ Today, it is almost 390 ppm – and it has been rising nearly 1.5 ppm annually, according to the data from Mauna Loa Observatory.³⁶ It is projected that from 1990 to 2100 the global mean temperature will rise from 1.9 to 2.9°C and the sea level will rise 46 to 58 cm. All of these forecasts indicate a serious environmental threat to humankind from climate change, generally challenging both researchers and policy makers.

Extreme events and natural disasters

Climate change encompasses changes in temperature coupled with changes in the frequency and intensity of weather patterns. While predicting changes in climate is an arduous task, predictions are necessary for guarding humankind against vulnerabilities brought about by extreme weather. Enhanced summer drought brings an increased risk of dryness, intense rainfall and flooding. This type of drought is seen currently and is projected to continue. In a warmer world, rainfall is concentrated into more intense events, with longer intervals of little rainfall.

Dew point is the temperature at constant pressure to which air must be cooled for water vapour to condense into water. This is a saturation temperature associated with humidity. At high relative humidity, the dew point is closer to the current air temperature; when dew point remains constant with elevated temperatures, relative humidity decreases. A warmer atmosphere will hold a larger quantity of water from increased evaporation if relative humidity remains constant. As water vapour is a GHG, the increase in absolute humidity will further warm the surface and atmosphere.³⁷

Major floods were witnessed in Kenya in the years 1997-1998 and 2006. The floods of 1997-1998, El-Nino rains, affected over one million people with economic costs of around \$1 billion due to damage of bridges and railways and communication infrastructure, spread of human and livestock diseases, and damage to agricultural produce.³⁸ An upward increment in CO_2 and temperatures was observed even in the following two years, an indicator that climate change is on an upward trend. High CO_2 concentrations imply an increase in temperature and erratic weather patterns.

It has also been documented that temperature and dew point changed in each of the three 10-year periods from 1980 to 2010. High water vapour increases humidity and further warms the surface and the atmosphere, hence the evidence of climate change and continued changes in future. The last 10 years have been warmer than the last 30 years; this will continue to hamper the agricultural sector in Kenya, which is rainfall dependent. Evidently, the Seven Folks Dams, Kenya's principal hydroelectric power-generation stations, have been affected by the increasing temperature.

The last 10 years have witnessed more extreme movement in temperature, dew point and CO_2 concentration. Negative skewing for the period indicates extreme observations away from the mean values. These negative values are observed in temperature, dew point and CO_2 concentration in the atmosphere. When the three sample periods are correlated, negative- or non-correlation indicates clear changes in climate over the last 30 years. Some districts in Kenya have had more extreme climate changes than others.

The rate of drought, flooding and natural disasters is on the increase. In accordance with the global warming hypotheses, an increase in atmospheric temperature was noted from the increase in CO_2 . Following the second hypothesis, the temperature increase could be the cause of the increases in flooding, drought and other natural disasters experienced in Kenya.

Effect of Climate Change on Agriculture

Crop response to climate change-related stresses

Sorghum is more drought resistant than other cereals such as maize.³⁹ Improving drought resistance in sorghum would further increase and stabilise grain production in regions of Africa with low rainfall and harsh environments and would contribute

to the food security of millions of poor people who depend on it. Some important physiological responses, such as leaf water potential (related to drought avoidance) and osmotic adjustment (related to drought tolerance), have been exploited to breed for increased yield potential under water stress.

Approaches to enhance crop yields in spite of climate change

Sustainable development in the productive system can be achieved through the integration of agricultural biodiversity, emerging technologies and conventional breeding methodologies that contribute to cereal crop improvement. The varieties of sorghum and other cereals must be developed with the required new traits, such as high input efficiency, tolerance of biotic and abiotic stresses, and improved nutritional quality, in order to increase agricultural productivity in rain-fed, marginal and stressed environments. The future outlook of sorghum improvement suggests that research must be focused on exploring the natural biodiversity in search of new genes and applying them through biotechnology to enhance the productivity of sorghum in stressed environments. Apart from identifying apomixes genes and using them to fix heterosis, developing male sterile entities with transgenic materials from hybrids and 'selfed' crops, growing parthenocarpic horticultural crops, and short cycling rapid improvement in forest and fruit trees covering annual and perennial crops are also desirable.

Research

Africa and other developing countries need to embrace research in order to develop more reliable sorghum and other cereals that can withstand the changing climatic conditions. In Kenya, varieties have been developed, such as gadam sorghum that are currently used for brewing alcohol. Researchers could aim to develop high-yielding varieties that are disease-resistant and pest-resistant.

Improved varieties

The replacement of old or absolute varieties of sorghum and other cereals with recently released high-yielding varieties is a major consideration in increasing agricultural production. It is necessary to develop early-maturing, high-yielding sorghum varieties that are stress tolerant, such as the gadam, serena and seredo sorghum varieties. Other crops include Nerica upland rice for arid and semi-arid lands (ASALs).

Irrigation

Since rainfall is a limiting factor, African nations should initiate irrigation schemes in order to address moisture stress. When water is a limiting factor, photosynthesis is reduced. This negatively affects photosynthetic production by the plant, which limits plant growth and yields.

As mentioned earlier, a change in weather patterns is likely to lead to a global rise in temperatures and increased emission of GHGs. This will ultimately lead to more weather extremes and will adversely affect water resources, resulting in droughts. The vagaries of weather are already having an impact on agriculture, weather systems and the health of both humans and livestock.

Cereal crops, particularly maize, are the major source of food in Africa. African nations should carry out research to document how increasing uncertainty will affect maize prices, the spread of disease and the productivity of crops.

Climate Change Coping Mechanism

Certain farming systems sequester more atmospheric GHGs than they emit and help counter the cause of weather changes. These farming systems are also more resilient to the weather extremes that play a role in global warming. Mechanisms used by these farming systems that help counter climate change are outlined below.

Increasing soil carbon, in a farming system, can result in minimal nutrient and pesticide run-off. For this reason African governments should select farming systems that ensure a quality environment geared towards improving soil health and increasing organic matter and the yield of the farming systems developed should be beneficial to all farmers.

Organic farming systems have a better soil structure and a higher level of humus and therefore use water more efficiently. Humus stores 20 times its weight in water, so rain is not lost through leaching or evaporation. These systems lose less soil and have better soil health.

Nitrogen is a major nutrient in the production of maize and other cereals. The use of synthetic nitrogenous fertiliser causes one of the major GHGs (nitrous oxide) and the leaching of water-soluble forms of this fertiliser pollutes aquatic systems. Very importantly, organic agricultural activity can help reverse climate change, as it emits fewer GHGs than conventional agricultural practices do. An increase in soil organic matter leads to a net decrease in GHGs as atmospheric CO₂ is converted into soil carbon.

It is evident that the two main climate change adaptation measures are to increase irrigation efficiency and change the maize cultivar.⁴⁰ The improvements in irrigation facility can provide a better water supply for crops and help maintain the current yield, but they have become less effective because of climatic change. After 2050, even a well-developed irrigation system, with an efficiency rate that is as high as 85 per cent, will not maintain a maize yield at current levels in the absence of other adaptations. Some of these adaptations are outlined below.

An adaptation suggestion is the adoption of new maize cultivars that are likely to suit the changed thermal conditions. As the maturity period of current cultivars is likely to be shortened by 20 to 30 days in the coming decades, alternative cultivars

(that have a longer grain-filling stage) should be introduced, since grain-filling plays a primary role in yield. Compared to optimising irrigation strategies, the option of cultivar switching is likely to be a long-term adaptation measure.

Another adaptation option could be switching to different crops; however, the effects would rely heavily on the practicability of technique transformation. Three factors that have probably contributed to improvement in yield and nitrogen fertiliser use efficiency are:⁴¹

- Increased stress tolerance of modern hybrids
- Improved crop cultural management
- Improved nitrogen management

Appreciable yields in maize production can be achieved, despite climatic variability, through: introduction and distribution of alternative cultivars with higher stress tolerance; improved crop and land management; and improved nitrogen management through the use of manure, legume rotation and residual soil nitrate. Also, improved nitrogen management includes applying nitrogen fertiliser in split.

Relevance of Hazard Risks to Various Stakeholders

Various stakeholders are involved in the decision-making process, from the individual to households, communities, political representatives, scientists/experts, the media and managers. The individual interests of each stakeholder affect his or her perception of the risks caused by hazards. A climatologist is interested in the climatic risk aspect of drought, floods, landslides, and other hazards and aims to acquire information that can be used in early warning systems. A social scientist is more concerned about how communities cope with the adverse consequences of drought, floods and wild fires. Both experts work on data, which may or may not be of sufficient quality and quantity for them to extract the information they need.

Factors that Affect the Perception of Risk

Level of exposure

The level of exposure of hazards can be assessed using the area and frequency of occurrence because these are easy to remember by the communities affected by the hazards. The history of the community settlement and the age of individuals within it may not include infrequent occurrences that pose unpleasant threat as people do not have any experience of these occurrences. In addition to personal experience, the ability to recall previous occurrences also plays a role, as local and recent events are easier to remember than older occurrences.

Education

The individual's experience, social grouping and level of technology awareness affect risk perception in a distinguishable manner. Rural people who have limited education may have less ability to make risk-related decisions; their perceptions of risk are probably controlled by individual exposure to the hazard that presents that risk.

Preventability

The degree to which the hazard and its effects are perceived as controllable or preventable is important. Community programmes help to inform the public that catastrophes can be averted and teach people how to take steps to protect themselves. Public awareness programmes are usually carried out in the context of disaster-alleviation programmes.

Availability of information

Ease of access to information about a given event makes it easy for the event to be judged as having occurred. The frequency of occurrence of an event increases public perception about how often it occurs. An important element reported by the media enhances its psychological risk perception in an individual. Knowledge of hazards is acquired more often from the news, for most people, than from first-hand encounters. The way the media describes hazards exaggerates risk perception, concentrating on rarer and dramatic events and making them look more in its reporting. The result is that these events are often perceived to be more recurrent than they actually are. Strong media reporting strongly influences public perceptions of the risk of exposure.

In rural societies, traditional oral stories are used to disseminate local history, values and norms. In contrast to knowledgeable groups in a prosperous community, people with irregular contact to news media may underrate the environmental hazards they face. There is evidence that availability of information influences risk perception considerably. Some societies that are without access to information on hazards appear to have a lower perception of the risk that natural hazards may affect them.⁴²

Dread

The perception of a hazard that some researchers term 'dread' is the horror of the hazard, its scale and consequences. It is clear that disasters have a high dread factor and are widely perceived as unpreventable. Images of disasters maiming, burning and spilling blood evoke a higher dread factor than those that show suffocation or drowning. Disasters that cause a large number of deaths are perceived as more dreadful than low-fatality catastrophes. Attributes of drama (e.g. sudden death or mass migration), context and experience influence recall. Dramatic information rich in death and disaster tends to be highly memorable. While perception of risk appears closely related to the dread factor it is only generally related to exposure levels or to

personal familiarity.⁴³ It is also clear that increased availability of genuine knowledge can provide insight into hazards and in this way provoke intentions to lessen vulnerability. It is therefore prudent to consider weather variation and the related consequences.

Case Studies

East Africa

The adverse impacts of weather variability are commonly felt by farming societies and industrialists in Kenya, particularly frequent droughts, flooding, power failure, and unreliable rainfall that culminates in crop failure and food insecurity. The communities at the foot of Mount Kenya have developed coping or mitigating skills in place of sound scientifically proven knowledge on climatic services.

The slopes on the eastern sides of the mountain, one of the most important water towers in Kenya, have been adversely affected by climate change. This area has the largest remaining forest in Kenya and the entire ecological unit is a key water source for the Ewaso Ng'iro and Tana rivers. These rivers supply to the national grid about 55 per cent of power in Kenya. Mount Kenya also hosts a wide variety of wildlife and diverse species of plants. It is therefore prudent to study the various coping strategies introduced or originally developed in this region to maintain this ecosystem sustainably, in spite of the challenging climate change.

Kenya, an agricultural country, has about 20 per cent of arable land, while the rest is arid and semi-arid. Changes in climate are a significant threat to its national development and environmental management and weaken its citizens' livelihood-support mechanism. Kenya's complex climate evidences wide variations coupled with strong seasonality.

Population growth

Kenya has developed a policy to help it become a middle-income economy. Its Vision 2030 blue-print anticipates that the Kenyan population will be at about 63 million by 2030 and 85 million by 2050.⁴⁴ Climate change will negatively affect food production in the country, putting its growing population in dire straits and negatively impacting economic growth in pursuit of Vision 2030. Not only will the climate lower production, but population growth will also reduce the area of arable land.⁴⁵ This affects highly productive areas with cash crops like tea and coffee – among others – lowering foreign exchange received from the sales of the produce. Like other developing countries with an economic growth model that favours industrial, economic and physical development at the cost of environmental management, Kenya is in a weak position for adjusting to drastic climate changes.

Deforestation is a common mechanism used to cater for a growing population's fuel needs. Analysts contend that reduced forest cover increases global warming

by 15 per cent.⁴⁶ The total area under forest in Kenya is estimated to be 49 million hectares, which represents about 2-3 per cent of the land area: this is below the international standard of 10 per cent.⁴⁷ The health of Kenyans will not be spared. Vector-borne human and animal diseases are likely to rise with an increase in climate change. Africa, with over 90 per cent of global mortality due to malaria, can expect the death rate to rise from this disease.⁴⁸ Water-borne diseases such as dysentery or cholera and heat-stress mortality may also increase. Population pressure, drought and other events are the main culprits behind increasing inter-ethnic conflict and fighting over resources.

Could this be supported by the global warming hypothesis? Kenya will continue to experience a warmer climate that could exacerbate evaporation and crop water deficits in an environment of declining rainfall.⁴⁹ Historical climate data indicates that the temperature on the African continent rose by 0.7°C in the twentieth Century.⁵⁰

The warmer climate has had a significant impact on Kenya already. In 1990, there were 18 glaciers on Mount Kenya; there are only seven left now.⁵¹ Many rivers in the central part of Kenya emanate from the mountain and are currently severely affected, reducing the amount of water supplied to the Seven Folks Dams, Kenya's principal hydroelectric power-generation stations.

Kenya is highly dependent on agriculture and rainfall is one of the most valuable natural resources needed for the sector to succeed. Meteorological data indicates wide annual rainfall variability in central Kenya.⁵² It was further noted that severe floods and dry spells had been common in East Africa recently. In 2009, the Stockholm Environment Institute (SEI) noted an expected increase in sea levels, a likely increase in rural population at risk for malaria and a general significant increase in periodic floods. Warm and dry periods are expected to persist in being interrupted by variability in rainfall seasons, with an increase in dry seasons.⁵³

Evidence shows that droughts occurred in the periods 1998-2000 and 2004-2005 and in 2009 and 2011. The economic cost associated with such extreme events was \$3 billion for the drought in 1998-2000 owing to loss of livestock, crops and forest; damage to fisheries; and decreased hydro-power water supply and industrial production.⁵⁴ East Africa has recently experienced anomalously strong rainfall, which caused flooding. The 2008-2009 droughts caused over 10 million people to have no food and drinking water. Frequent natural disasters are observed in Kenya, 70 per cent of which are weather related. The drought oscillation period in the past used to recur every five years. The interval between droughts has now reduced to two to three years.⁵⁵ In East Africa, drought events have increased from 3 per year in the 1980s, to 7 in the 1990s and 10 in the period 2000-2006.⁵⁶

Sub-Saharan Africa

The Sahel is highly vulnerable to climate change in Africa south of the Sahara due to its location at the southern edge of the Sahara Desert. The droughts of the 1970s

and 1980s represented a testing moment for countries in this region and droughts are anticipated to be worse in the twenty-first Century. The UNFCCC and the Kyoto Protocol emphasise mitigation and adaptation when dealing with issues related to weather variation. Mitigation deals with lessening GHGs released, in order to prevent further warming. Adaptation targets managing the impact of the problem of climate change.⁵⁷

The current understanding of climate change is derived from reports from the IPCC, the National Commissions and direct observation on the ground. The countries in the Sahel contribute a small amount of the global GHG emissions. However, they suffer much more from adverse effects of climate change due to their close proximity to the Sahara Desert and their low adaptive capacity.

Sahel countries rely mainly on agriculture for their livelihood. In these regions, agriculture remains highly underdeveloped, being characterised by: (1) dependency on rainfall; (2) low to no mechanisation; (3) low use of improved seeds and fertilisers; and (4) poor linkage to markets. This means that the agricultural industry in the Sahel region is vulnerable to climate variability.

Southern Africa

In 2007, a combination of drought and high temperature caused significant crop damage in South Africa. The maize yield dropped to a record low yield of 6 million tons in April. South Africa is susceptible to climate variability and the country is threatened by desertification because of serious degradation of land and water resources and a lack of biodiversity. Managing climate variability must become the norm rather than the exception. Elsewhere in southern Africa, prolonged drought affected the whole of Botswana from 1981 to 1986 due to a period of below-average rainfall years; this caused large-scale loss of livestock and wildlife.

In 1991/1992, the sub-region experienced another devastating drought. Zimbabwe experienced a great loss of crops and livestock and most areas were almost reduced to desert conditions due to the worst drought. Drought also caused water and electricity shortages that resulted in manufacturing output in Zimbabwe declining by 9.3 per cent.⁵⁸ This 1991/92 drought in southern Africa had an adverse effect on about 1.3 million people. Civil war exacerbated the impact of drought, causing widespread loss of livestock and food supplies, and environmental degradation. It is reported that, in 1992, drought in South Africa caused the loss of an estimated 50 000 jobs in the agricultural sector and a further 20 000 jobs in related sectors, which affected over 250 000 people.⁵⁹

Conclusion

Climate change is a long-term change in temperature, wind and precipitation. This change is influenced by the emission of GHGs from burning fossil fuels and

anthropogenic activities. High temperatures, rising sea levels, melting ice and increased ocean acidity are already noticeable. These occurrences are bound to continue in the future. Agriculture will be the most affected, especially in the dry lands of sub-Saharan Africa, owing to several abiotic stresses, among them water, temperature and nutrition.

A need exists to plan ahead, rather than use uncertainty as a reason for inaction. Genetic diversity should be employed to develop a mechanism that eliminates internal stresses and that minimises drought injury. In order to enhance photosynthesis, irrigation and reflective chemicals, such as kaolin, which lowers the adverse impact of evapotranspiration on carbohydrate synthesis, need to be introduced. A combination of mitigation and adaptive measures should be put in place to cope with the adverse effects of climate change.⁶⁰

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Part III

Vulnerability to Hazards

CHAPTER 11

Pollution Vulnerability of Coastal Ecosystems and Contingency Planning Imperatives

Nigerian Case Study

Effiom Antia

Introduction

Coastal regions are among the most valuable yet vulnerable regions on the Earth's surface. They are naturally complex, being the transition between the terrestrial and ocean realms. A major hazard confronting coastal regions is pollution. There is a general belief that high population density patterns in coastal regions, world-wide, contribute to the high pollution vulnerability of these regions.

Pollutants in the coastal regions may be natural or human-induced in origin, visible or detected only through instrumentation. They may show a point or non-point source and may be confined in space or cross boundaries. Furthermore, their occurrence and concentration may be catastrophic or build steadily.

The most common sources of pollution in sub-Saharan African coastal regions are typically a result of untreated industrial effluent and domestic sewage outfalls, run-off from fertiliser-enhanced agricultural landscapes, leachates from dump sites or mining sites, insanitary land and waterway use, oil spillage and ballast water discharge, and atmospheric emissions including gas flaring. A review report,¹ for instance, indicates that there are very few sub-Saharan African nations where the quality of surface water, sediments and biological resources are not deterioration-prone as a consequence of human-induced pollution.

Pollution consequences are adverse and diverse, but commonly impact on human and ecosystem health, leading to impoverishment and heightened poverty in coastal communities. These consequences are generally considered to be most dramatic in sub-Saharan Africa, where the human development index (HDI) ranking is characteristically low, as evidenced by the fact that only two nations in the sub-region (Seychelles and Mauritius) are ranked among the top 100 developed nations in a global assessment of the HDI of 178 countries.²

In light of improved understanding of coastal ecosystem vulnerability and pollutant dynamics, the adverse effects of environmental pollution must not be allowed

to persist in the sub-region. This is because environmental pollution contributes significantly to the poor indices of human development that prevail in the sub-region, notably: low life expectancy and poverty.

Lessons learnt from the Nigerian coastal region form the focus of this report. Given that the underlying driver of pollutant severity in a coastal ecosystem is its natural self-flushing potential, the Nigerian results presented in this chapter can be beneficially applied to dynamically comparable coastal regions of sub-Saharan Africa.

The coastal literature of most sub-Saharan African states indicates that pollution investigations are largely localised, have limited evaluated parameters, preclude inter-ecosystem comparisons and typically are devoid of elements of contingency planning. The dynamics of the coastal region and the related problems of trans-boundary pollutant transport are compelling reasons for shifting the focus from localised studies (for example, Lagos Lagoon in Nigeria,³ Ghanaian lagoons of Sakumo and Kpeshie⁴ and the beaches of Ghana,⁵ the beaches of Cameroon⁶ and Kenya⁷ and recreational water quality of South Africa)⁸ to ecosystem-wide vulnerability assessments, ranking and modelling.^{9,10,11} The 1981 Abidjan Convention is an example of an initiative that recognises the need to fight transboundary pollution jointly in the coastal and marine areas of West and Central Africa.

With increasing urbanisation, industrialisation and population growth in the coastal regions, the quality of coastal environmental health in the years ahead will depend strongly on improved knowledge of ecosystem health status; natural and technology-based pollution remediation strategies; and regional enforcement of international best-practice in pollution control.

Coastal setting of Nigeria

The Nigerian coast is about 800 km long (Figure 11.1), and has natural features that are consistent with outlined global models that are based on tectonic setting, coastal oceanographic regime and geomorphologic condition.^{12,13,14} It is a low-lying physiography embedded within the passive margin of the African plate.

Low tidal regime (< 1 m) and strong longshore currents (such as those observed in the westernmost coastal segment) favour the formation of the barrier-lagoon coastal morphology. The barrier beach sediments are medium- to coarse-grained sands as are their other West African counterparts, while the lagoons (typically <3 m deep) have a range of finer-grained sands and clays. The arcuate Niger Delta (formed by the tributaries of the River Niger) is the most enigmatic feature, occupying about 50 per cent of the coastline length. It is flanked to the east by a high energy, mesotidal strand-plain fine-grained sandy coast and to the west by a microtidal low-energy transgressive muddy coast.

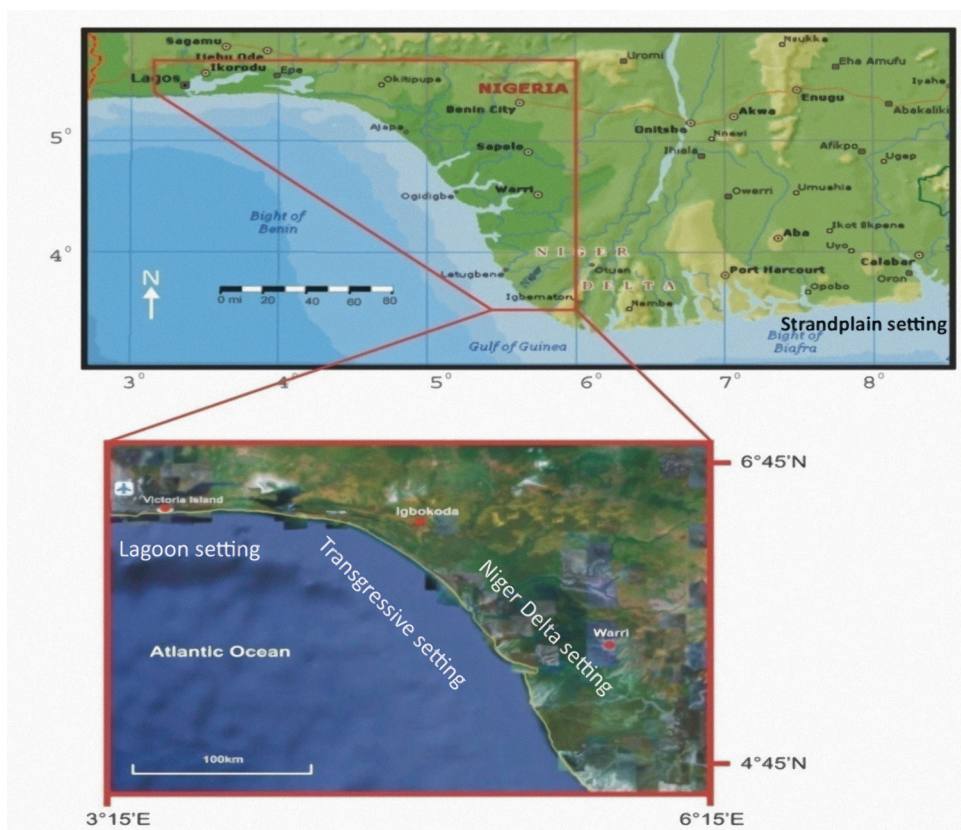


Figure 11.1: Outline of the Nigerian coast (imagery from Google Earth).

Some 20 estuaries incise the deltaic coastline, each with differently shaped ebb-tidal deltas or mouth bars. Backing the coastline are brackish-water mud swamps, which are dissected by a complex tidal creek network and vegetated, for the most part, by mangroves.

In Nigeria, as in most other maritime nations of sub-Saharan Africa, industries are most commonly concentrated in the coastal region, largely because of easy access to the sea port but also due to proximity to raw materials. The presence of these industries attracts other commercial activities, which, collectively, stimulate growth in both local and national economies. Consequently, a high rate of human migration to coastal regions is a common trend in the sub-region, the primary reason being to take advantage of the employment and economic opportunities that the industries and supporting enterprises offer.

The above scenario, coupled with the coastal location of oil exploration, storage and refining infrastructure, accounts for Nigeria's high coastal population density, generally estimated at three times the national average of 160 people/km². Unfortunately, the upsurge in industrialisation and population growth in many

coastal locations is almost matched, on average, by increased levels of environmental pollution over time.

The pollution situation of the coastal region of Nigeria has been aggravated over time by gas flaring and occasional accidental oil spillage incidents, but more recently through wilful oil spillage events, particularly in the Niger Delta region. It was shown that over a 25-year period (1976-2001), a total of 6 817 crude oil spill incidents (averaging five spills per week and amounting to three million barrels) occurred in Nigeria's coastal zone, with over 70 per cent not being recovered.¹⁵ The coastal environmental health status is further worsened by unabated domestic discharge and by undetected trans-boundary influx of pollutants.

The low HDI categorisation of Nigeria, alongside 60 per cent of the maritime nations of sub-Saharan Africa,¹⁵ is a direct reflection of the prevailing poor living standard and deficiencies in major public infrastructure, of which pollution containment and control are a major component.

While the HDI report showed Nigeria's categorisation to be persistently low (<0.466) within a 30-year period (1975-2005), some other maritime nations in the sub-region, such as Ghana, Cameroon, Gabon, South Africa, Kenya, Mauritius, and Seychelles were ranked in the medium HDI category. No nation in the sub-region ranked in the high HDI category.

Coastal Pollution Case Study

For illustrative and instructive purposes, emphasis is on beach, mangrove swamp, lagoon and fluvio-estuarine ecosystems.

Beach Ecosystem

Beaches act as natural buffers against a wave overtopping tendency, which, besides the physical destruction it can cause, can also transport ocean-borne pollutants to back-barrier productive swamp ecosystems. Recreational sites and resorts can in this way also be polluted, leading to tourists abandoning the area and considerable loss in revenue. Ocean-borne crude oil spillages, as reflected in stranded tar balls on beaches, have been documented in Nigeria¹⁷ and on the coastlines of Kenya,¹⁸ Ghana¹⁹ and Cameroon.²⁰

At several beach sites in Nigeria, for example Alfa Beach on the western coastal segment (Figure 11.2), pollution load on beaches is due to the wilful action of people dumping litter directly into nearshore water bodies or on land within reach of tidal current transport systems.

In other instances, unsanitary practices on beaches that result in faecal pollution are of growing concern. Figure 11.3 indicates the quasi-sinusoidal variation pattern of faecal pollution over a tidal cycle in the surf zone waters of Itak Abasi Beach on the southeastern coast of Nigeria. Surf zone station 1, which is proximal to Qua Iboe

River estuary, shows more elevated values than the more distal (150 m) station 2. Although the faecal coliform count (FCC) values are within the target range for full contact recreational use of a number guidelines,²¹ the health risk from gastrointestinal illness exists.



Figure 11.2: Debris and litter on Alfa Beach, southwest Nigeria.

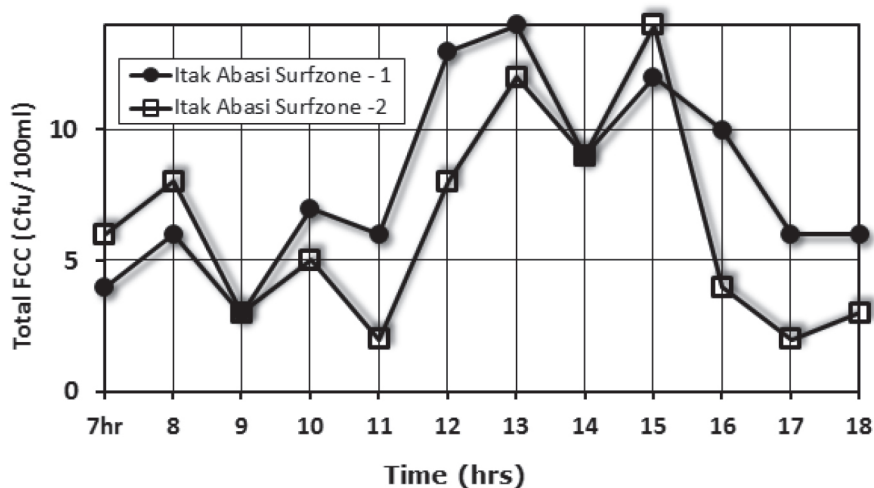


Figure 11.3: Tidal cycle variation in total faecal coliform count (FCC) in surf zone waters of Itak Beach, southeast Nigeria on 1 March 2012.²²

In the case of particulate pollutants documented along a mesotidal modally intermediate beach, beach vulnerability to pollution was conceptualised to be primarily a function of the morphodynamic state of both the beach and surf zone,²³ with morphodynamic conditions evaluated as previously defined.²⁴ A combination of a dissipative surf zone and a reflective-prone beach will facilitate self-cleansing of stranded pollutants. Brief time changes in these morphodynamic conditions are driven by daily tidal oscillation.

Wide surf zones and multiple spilling breakers that suppress massive particulate pollutant transport to shore, especially under oblique wave conditions, characterise low tide. By contrast, the rising tide is associated with an increase in plunging breakers in a narrower surf zone. The higher energy density in this reflective-prone surf zone can translate to intense wave swash, which can transport entrained particulates up the beach profile, as depicted on the medium- to coarse-grained Alfa Beach (Figure 11.2).

Given the ease of beach scarping and the offshore-transport tendency of reflective-prone beaches, self-cleansing of stranded pollutant particulates will generally be higher on these beaches than on their dissipative counterparts.

Mangrove Swamp Ecosystem

An inventory of different swamp sediment quality parameters was conducted, based on field sampling conducted in January and February 2010.^{25,26} The mean concentration of total hydrocarbons in surface swamp sediments in the Niger Delta region is given in Figure 11.4; it shows a regional average of 13.5 ppm, with concentrations of above the regional average occurring towards the eastern coastal segment of the strand-plain morphology. This trend is considered to reflect the increasing coastwise tidal range (and tidal incursion) in the eastward direction.

Given that the regional net longshore current velocity direction is also eastward, once hydrocarbon pollutants are discharged into or flushed out to the nearshore region of the westernmost and central to eastern coastal segments, their transport trajectory will be essentially eastwards.

However, because of the more intense tidal incursion in the easternmost segment, the hydrocarbons are likely to be dispersed more upstream, where they become trapped within the fine sediments of the expansive tidal flats and swamps.

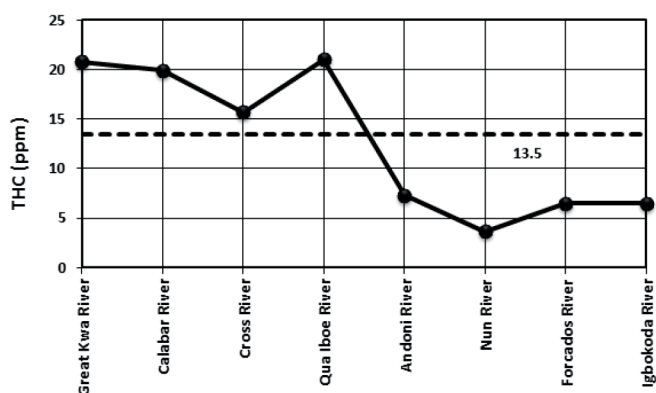


Figure 11.4: Coastwise (east – west) variation in mean total hydrocarbon concentration (THC) in Nigerian swamp surface sediments, based on 2010 field sampling.²⁷

Analysing the concentration of the hydrocarbon-utilising bacteria (HUB) in swamp sediments (Figure 11.5) is quite instructive because values that are higher than the regional average of 53 cfu/ml/g are observed in the easternmost coastal segment, where the hydrocarbon concentration is also highest. The Igbokoda swamp sediment is an exception in that it has high HUB values that do not correspond to the relatively low hydrocarbon concentration. Furthermore, it can be observed in Figures 11.6 and 11.7 that the concentrations of zinc and iron in swamp sediments are also markedly higher than the regional averages of 858 ppm and 68 241 ppm, respectively, toward the easternmost segment.

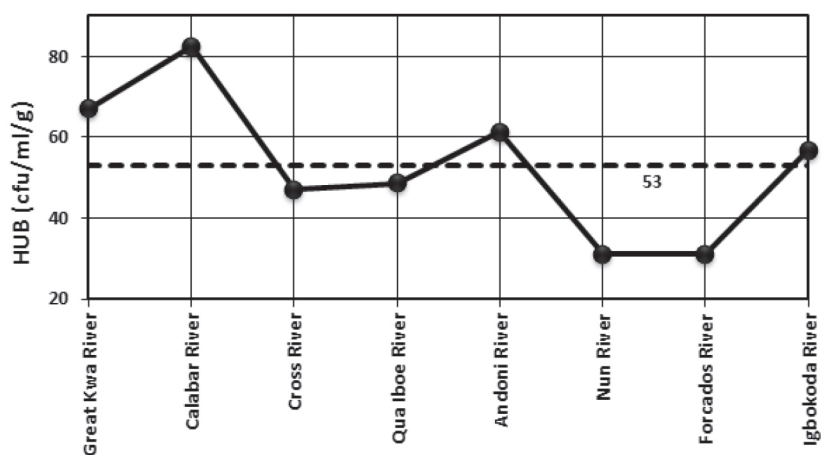


Figure 11.5: Coastwise (east – west) variation in mean concentration of hydrocarbon-utilising bacteria (HUB) in the surface sediments of Nigerian swamps, based on 2010 field sampling.²⁸

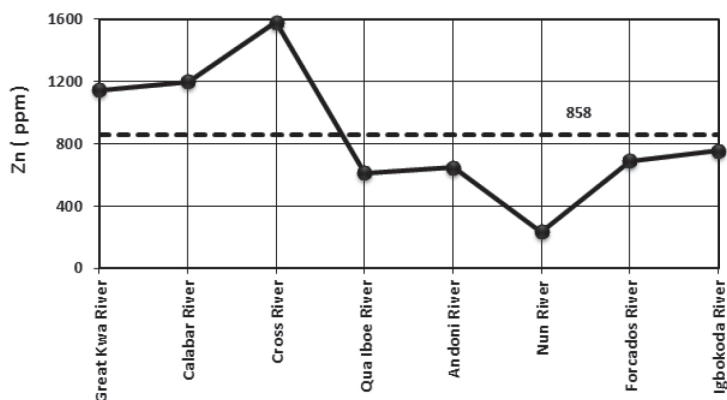


Figure 11.6: Coastwise (east – west) variation in mean concentration of zinc in Nigerian swamp surface sediments, based on 2010 field sampling.²⁹

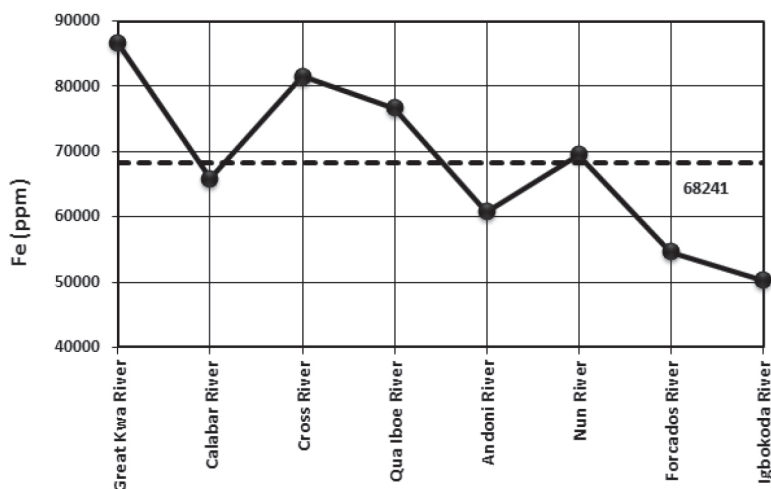


Figure 11.7: Coastwise (east – west) variation in mean concentration of iron in Nigerian swamp surface sediments, based on 2010 field sampling.³⁰

When swamp sediment samples retrieved from two-metre long cores were analysed, the swamps in the Niger Delta showed a higher average total hydrocarbon concentration (THC) in surface sediments than at the mid-depth (1 m) and bottom (2 m) (Figure 11.8). The HUB values showed a comparable trend (Figure 11.9). The high average hydrocarbon concentration (19.6 ppm) at 2 m below the surface is suggestive of environmental degradation with health consequences, especially groundwater contamination.

In contrast, Figures 11.10 and 11.11 show that average iron and nickel concentrations in the swamp sediments increase with depth. The concentrations at depth, in particular, may contribute to the poor quality of groundwater generally noted at some locations in the Niger Delta coastal region.

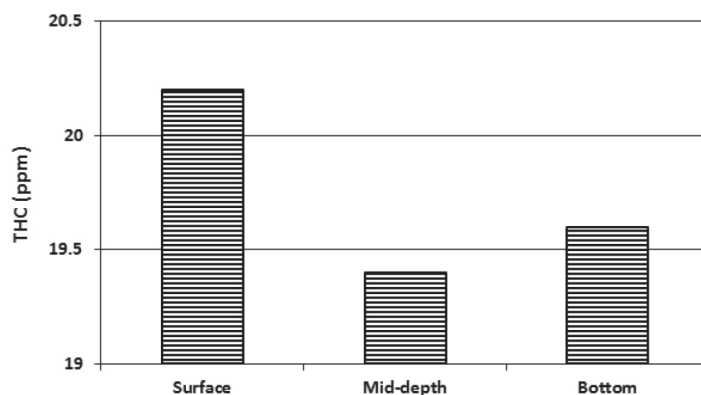


Figure 11.8: Average concentration of total hydrocarbons in surface, mid-depth (1 m) and bottom (2 m) sediments of swamps in the Niger Delta region.³¹

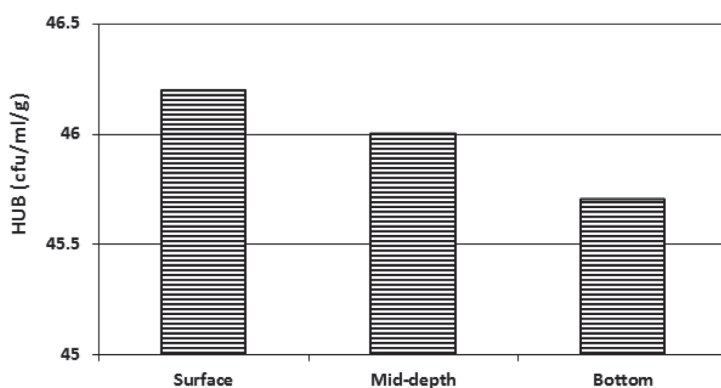


Figure 11.9: Average counts of HUB in surface, mid-depth (1 m) and bottom (2 m) sediments of swamps in the Niger Delta region.³²

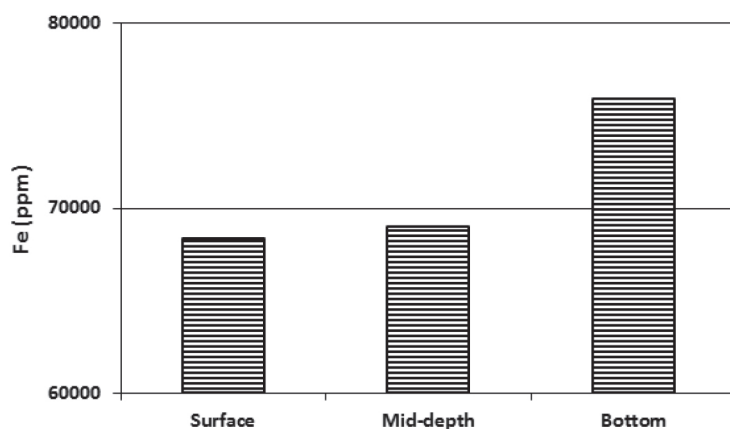


Figure 11.10: Average concentration of iron in surface, mid-depth (1 m) and bottom (2 m) sediments of swamps in the Niger Delta region.³³

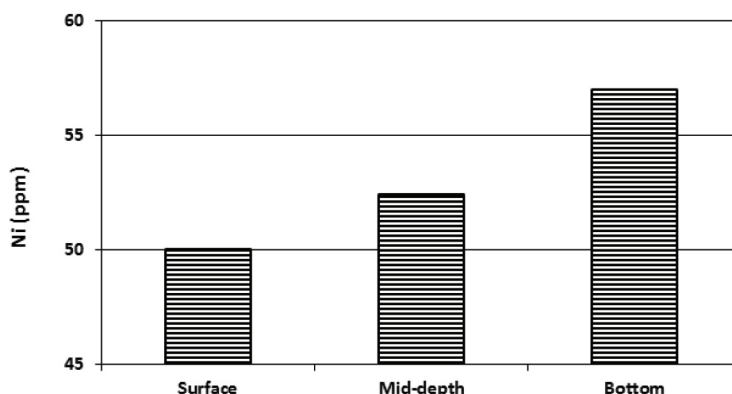


Figure 11.11: Average concentration of nickel in surface, mid-depth (1 m) and bottom (2 m) sediments of swamps in the Niger Delta region.³⁴

From a nationwide coastal perspective, there is a clear indication of heavier pollution of evaluated sediment quality parameters in Niger Delta region swamps than in the coastal lagoon counterparts (Figure 11.12), the latter exemplified by Badagry Lagoon, which is located in the westernmost coastal segment.

With surface sediments, the Niger Delta swamps have a 1.3-2.6 times higher concentration of the sediment quality parameters. Zinc and manganese concentrations in sediments from Niger Delta swamps exceeded the concentrations of sediment from the lagoon swamp by a factor of two. The noted high concentration of zinc is likely to be related to the corroding effects of gas flaring-induced acid rain falling on the zinc roof sheets of buildings in the Niger Delta region.

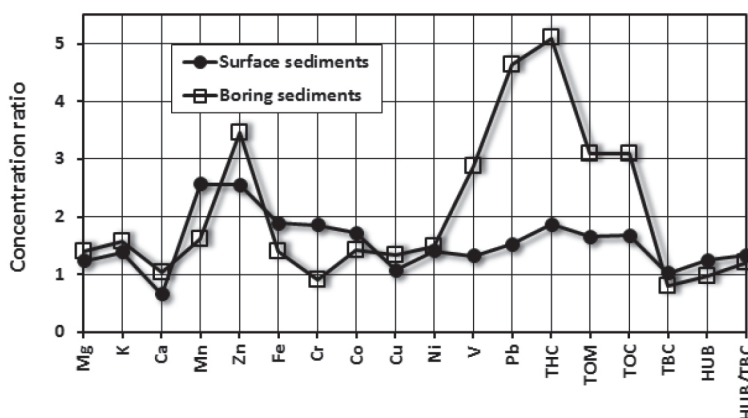


Figure 11.12: Swamp ratios (Niger Delta: Badagry Lagoon) of average concentrations of sediment quality parameters for surface sediments and borings, based on 2010 field sampling.^{35,36}

In relation to bore-averaged sediment quality parameters, sediments from the Niger Delta swamps also showed higher concentrations than the coastal lagoon counterpart. Most instructive are lead and THCs, which indicated a >4-fold higher concentration in the Niger Delta region swamps.

Sampling from the microtidal transgressive mud setting (exemplified by Igbokoda on the southwest coast) showed sediment quality parameters to be more concentrated in swamp muds when compared to the river counterparts (Figure 11.13). Notable are excess concentrations (>100 per cent) in swamp sediments, relative to the river, for lead, nickel and total hydrocarbons. This clearly shows that swamp ecosystems are more vulnerable to pollution because of the high residence times of pollutants. This is a result of the low energy condition in swamps, which limits re-suspension and transport of particle-adsorbed pollutants. The total bacterial count (TBC) and HUB count in both swamp areas were, however, comparable.

Lagoon and Fluvio-Estuarine Ecosystem

An inventory of lagoon and the fluvio-estuarine sediment quality parameters was undertaken on the basis of field sampling conducted mostly between August and October 2008.^{37,38} A comparison of concentration profiles of various sediment quality parameter ratios shows that, for Mg/K, the sediments of lagoons did not have a well-defined mode, but tended to be bi-modal (Figure 11.14) when compared with their river counterparts (Figure 11.15). However, concentration ratios of 1.5 to 3.0 were typical of both fluvial and lagoon sediments. The Calabar River and Bonny River were the exceptions of this modal class. For other rivers and lagoons, marked variations from this modal class in future investigations will invariably be indicative of a change in environmental health, probably as a result of anthropogenic influxes.

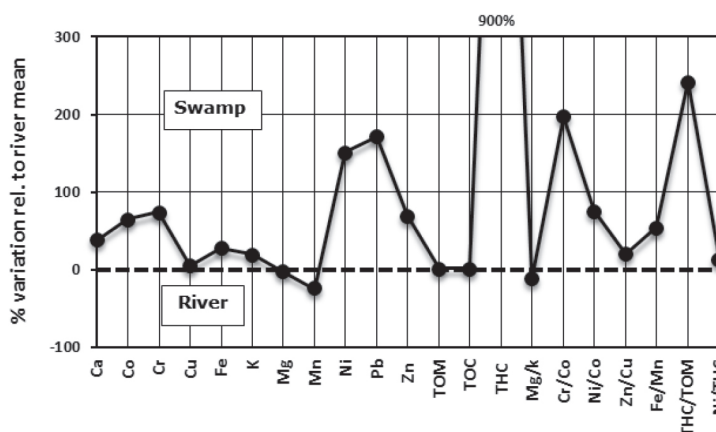


Figure 11.13: Percentage variation of sediment quality parameter concentrations in Igbokoda swamp muds relative to the mean concentration for river mud counterparts.³⁹

A comparison of concentration profiles of the Fe/Mn ratio shows that lagoon sediments have well-defined modal classes of 30 to 45 and 45 to 60 (Figure 11.16), while their river counterparts (Figure 11.17) show a very broad range of modal classes. The fluvial concentration profiles are not typically a consequence of geological or natural attributes, especially if one compares adjoining rivers that traverse similar geological terrain.

Thus, it appears that anthropogenic influence is expressed in the concentration profiles of the various rivers. As in the Mg/K concentration ratio profile, the presented Fe/Mn concentration profile for each river could serve as a baseline for comparing future patterns. This is because any significant influx of any component of the concentration ratio will modify the concentration profile pattern by: creating additional modal classes; causing a shift in the existing primary modal class to a higher concentration range; or increasing the frequency of occurrence of an existing modal class.

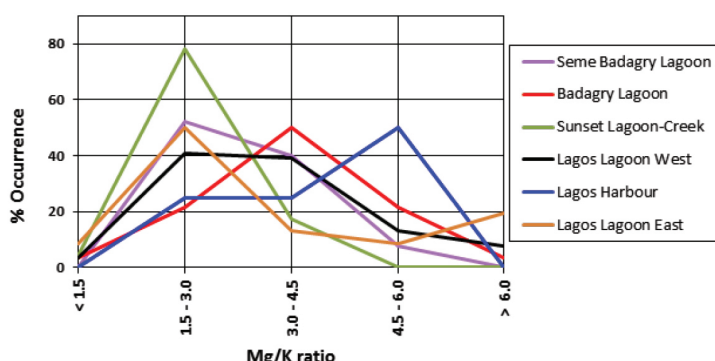


Figure 11.14: Frequency distribution of Mg/K ratio in some Nigerian lagoon sediment samples, based on 2008 sampling.⁴⁰

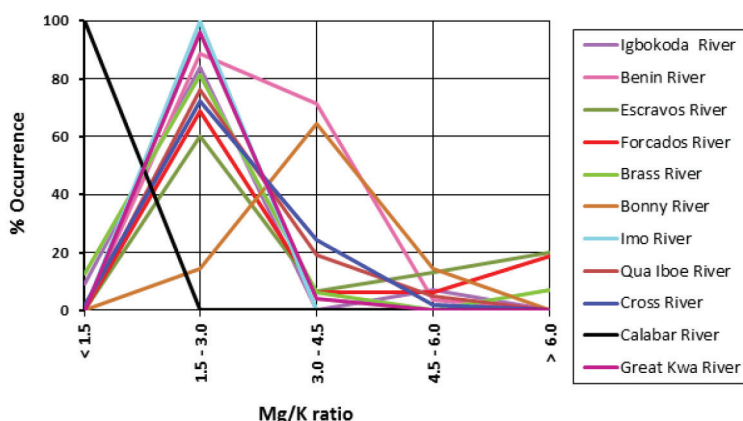


Figure 11.15: Frequency distribution of Mg/K ratio in some Nigerian fluvial and estuarine sediment samples, based on 2008 sampling.^{41,42}

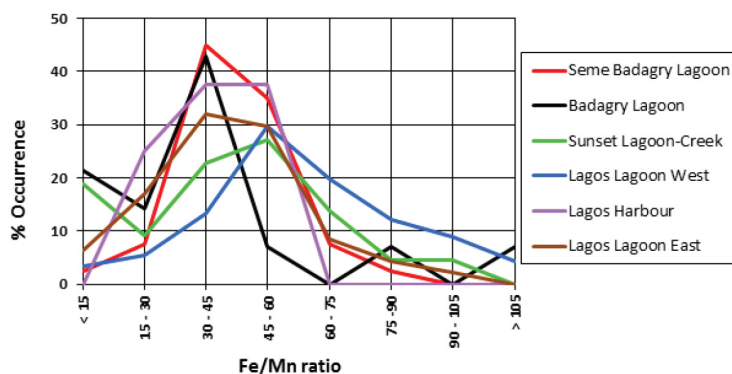


Figure 11.16: Frequency distribution of Fe/Mn ratio in some Nigerian lagoon sediment samples based on 2008 sampling.⁴³

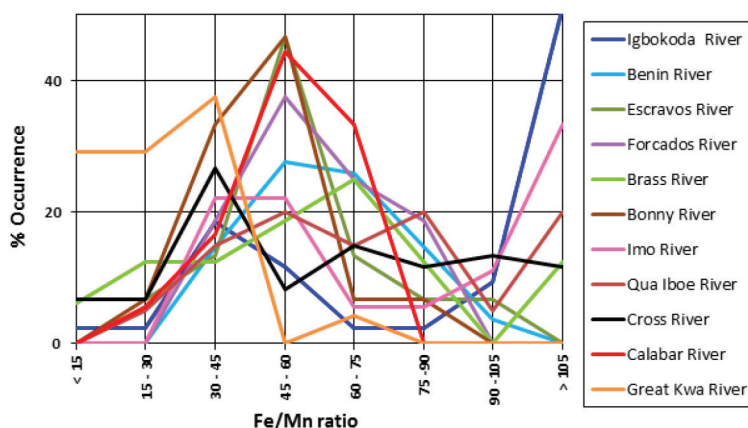


Figure 11.17: Frequency distribution of Fe/Mn ratio in some Nigerian fluvial and estuarine sediment samples, based on 2008 sampling.^{44,45}

A comparison of Cr/Co concentration ratio profiles for lagoon sediment samples (Figure 11.18) did not show a consistent pattern, in spite of their spatially contiguous nature. This is suggestive of varying anthropogenic inputs of chromium and cobalt and of the generally poor flushing action of the lagoons. By contrast, most of the rivers show a well-defined unimodal distribution pattern, with a Cr/Co modal class ratio of 3 to 4.5 (Figure 11.19). The Escravos River estuary was markedly different in being bimodal, which is suggestive of anthropogenic input. The second mode probably relates to a point source discharge of effluents enriched with chromium.

As a further guide to future assessment of environmental changes in the lagoon and fluvio-estuarine sediments, the mean Mg/Ca concentration ratio is presented in Figure 11.20. This ratio is one of the best discriminators between the lagoon and fluvio-estuarine sediments in the Nigerian coastal setting. With the exception of the Bonny River estuary, which is fringed by major industrial enterprises, the

fluvio-estuarine sediment samples showed higher Mg/Ca ratios than the lagoon sediment samples.

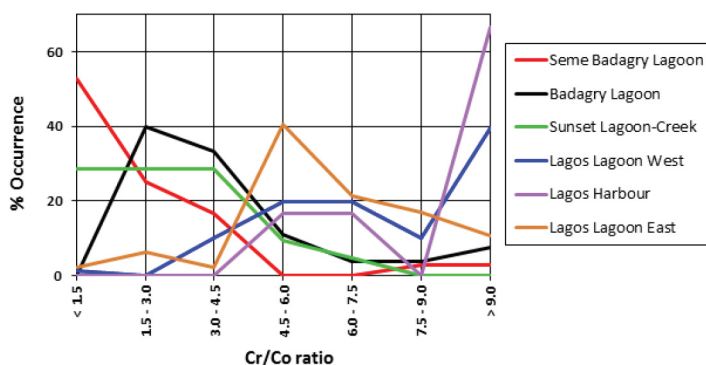


Figure 11.18: Frequency distribution of Cr/Co ratio in some Nigerian lagoon sediment samples, based on 2008 sampling.⁴⁶

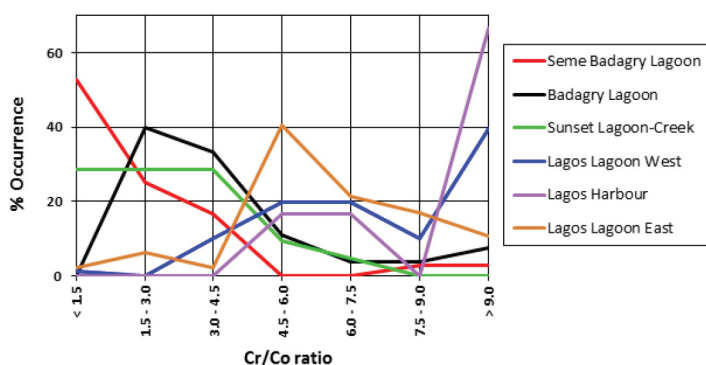


Figure 11.19: Frequency distribution of Cr/Co ratio in some Nigerian fluvial and estuarine sediment samples based on 2008 sampling.^{47,48}

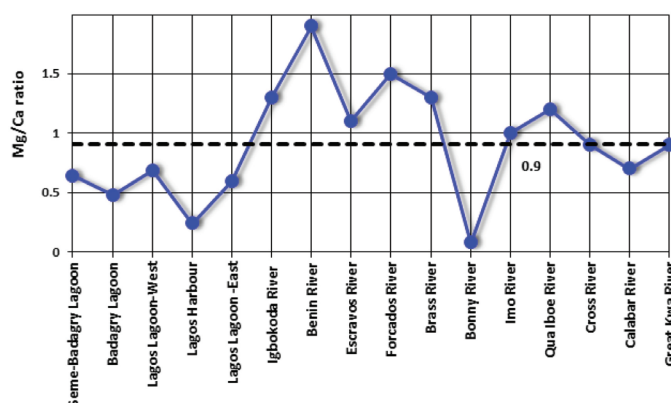


Figure 11.20: Coastwise (west – east) variation in mean concentration of the Mg/Ca ratio in Nigerian lagoon and fluvio-estuarine surface sediment samples based, on 2008 sampling.^{49,50}

The results also reflect the geology of the catchment areas of the water bodies. Limestone enriched with calcium forms part of the geology of the lagoon setting in the western coastal segment as well as the easternmost coastal setting of the Calabar River, Cross River and Great Kwa River, hence their lower-than-average ratios.

To illustrate the disparities in the sediment quality relationships, a case study of the contiguous Calabar and Great Kwa rivers is presented in Figure 11.21. The correlation chart depicts parameter pairs with a positive and inverse correlation coefficient > 0.7 . It can be observed that of the total of 94 entries in the chart, only nine per cent of the parameter pairs are common to both rivers. These are Mg – Ca, Mg – Cr, Mg – Co, K – Ca, K – Co, Ca – Cr, Fe – Cd, Mo – TOM (total organic matter).

This result indicates that the natural occurrence of and relationship between the sediment quality parameters in both adjoining rivers vary markedly. The disequilibrium between parameter pairs (and hence non-occurrence in the correlation chart) may be a result of anthropogenic influx. However, this perspective will need further exploration in future studies as it holds the key to comparative pollution studies in coastal sedimentary environments.

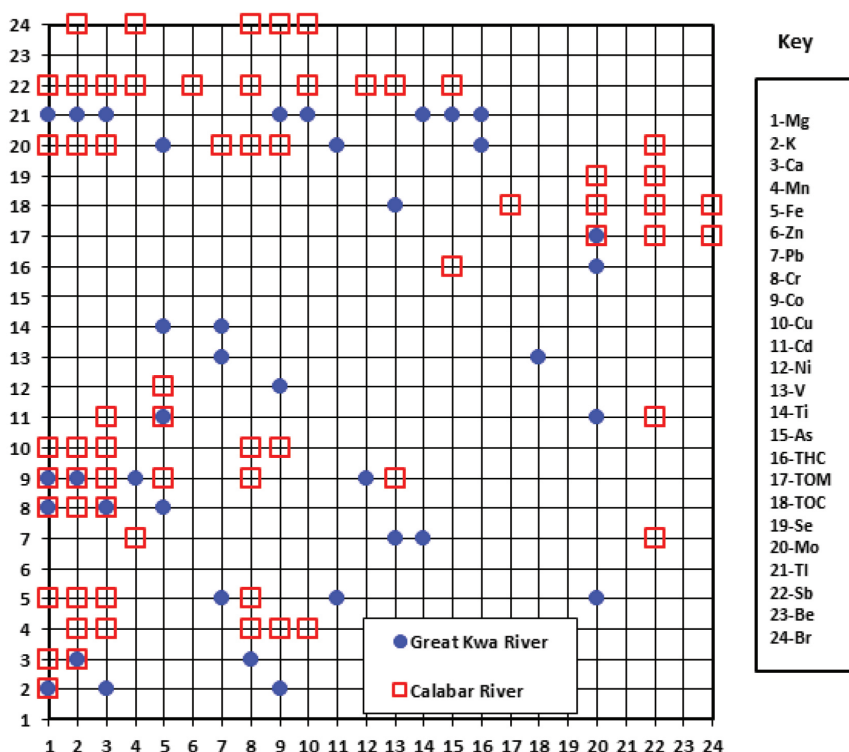


Figure 11.21: Correlation chart of sediment quality parameters for the Calabar River and Great Kwa River, southeastern Nigeria, based on 2008 sampling.⁵¹

Contingency Planning

Tidal-driven coastal water bodies that are polluted pose particular problems, especially where the polluting incident is regional or trans-boundary in nature and hence impacts many tidal water channels almost simultaneously. The problem emanates from the observation that such tidal waters are characterised by reversing flow, which may retain the pollutants in the water column over varying durations of time.

The ease and rapidity of flushing out pollutants in tidal water channels are clearly a major factor in coastal contingency planning. Tidal excursion length is one such hydrodynamic parameter that expresses the ability of a tidal water system to cleanse itself of entrained pollutants naturally.

Results of the investigations of two contiguous estuaries in southeastern Nigeria: the Imo River and the Qua Iboe River, are given in Figure 11.22. The most important facts to emerge from the investigation are that the net tidal excursion varies sinusoidally in relation to the lunar cycle, with a maximum net excursion length southward (oceanward) occurring at about spring tide and the minimum occurring at neap tide. The more easterly Qua Iboe River estuary shows higher net excursion lengths than the Imo River estuary because of the eastward-increasing mean tidal range along the coastal setting. Generally, their peak net excursion length is in the order of 2.5 to 4.5 km.

In the case of the surf zone of Ibeno Beach on the southeastern coast of Nigeria, the results given in Figure 11.23 show that tidal influence can moderate the pattern of longshore currents generated by obliquely breaking waves in the surf zone. The tidal effect is such that this otherwise unidirectional longshore current becomes bi-directional (east- and west-flowing) within tidal frequencies.

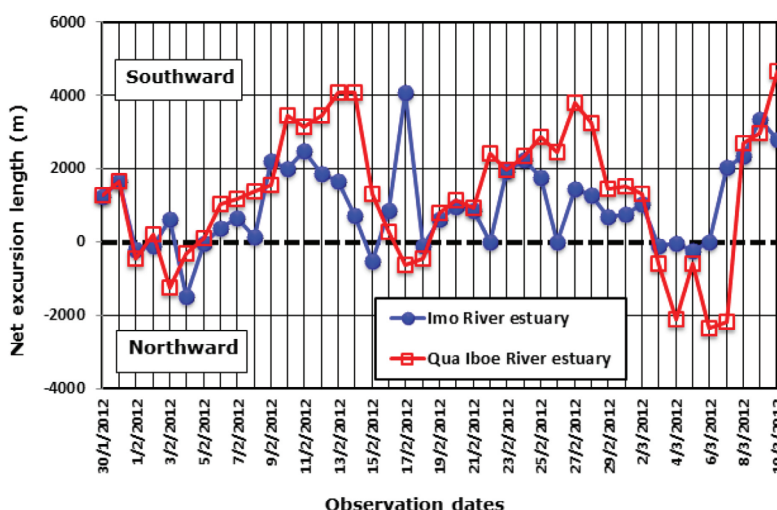


Figure 11.22: Time-series variation in tidal cycle - net excursion length of the Imo River estuary and Qua Iboe River estuary, southeastern Nigeria.⁵²

Unlike in the case of the estuaries, where the net excursion lengths were southward-asymmetric, the surf zone counterpart shows comparable eastward and westward net excursion lengths, with net excursion length peaks in the range of 500 to 1 000 m. The peak eastward excursion lengths coincide with spring tide, while their westward counterparts occur at about neap tide. However, for the aforementioned information to be of practical importance as a contingency planning tool, net excursion length patterns must be obtained for all the principal water bodies and coastal sites, and then ranked relative to their flushing potentials.

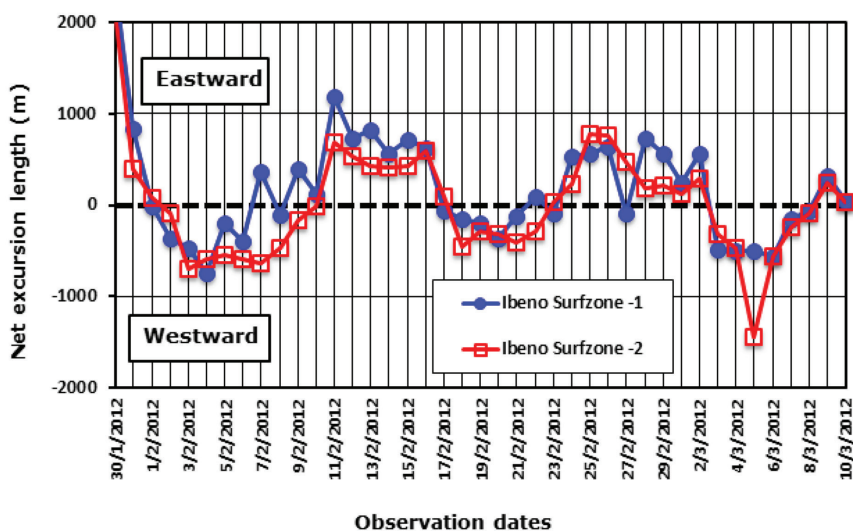


Figure 11.23: Time-series variation in tidal cycle - net excursion length of surf zone stations of Ibeno Beach, southeastern Nigeria.⁵³

Conclusion

Pollution is a growing threat to the quality and productivity of the coastal environments of most sub-Saharan African nations. While some localised investigations into the pollution status of coastal environments have been conducted, these are not sufficiently instructive for the purposes of understanding pollutant dynamics and inter- and intra-ecosystem vulnerability. Case studies of Nigerian coastal ecosystems show variation in ecosystem pollution vulnerability, which is mostly a function of the hydrodynamic condition and can be defined by their flushing or self-cleansing potentials.

Efficiency of estuarine flushing (directed downstream towards the ocean) of pollutants will be at the maximum at spring tide and diminish significantly to near zero or be directed upstream at neap tide.

Besides providing some baseline data on sediment quality parameters, this chapter has also highlighted the potential of concentration ratio profiles and the

correlation chart for defining pollution trends and inter-relationships at ecosystem level. From the point of view of trans-boundary pollution events, ecosystem-based contingency planning needs to take place at national and regional levels.

Acknowledgements

The contributions of my colleagues at the National Centre for Marine Geosciences, field and laboratory personnel as well as many consultants to the implementation of our geochemical research projects of which this presentation is an offshoot is gratefully acknowledged. The support given by the Director General of the Nigerian Geological Survey Agency to these research efforts is most appreciated as well as the technical and editorial inputs of the reviewers of this chapter.

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CHAPTER 12

Coastal Vulnerability

Groundwater Signatures from the Nigerian Coast

Effiom Antia

Introduction

Coastal vulnerability is an outcome of a myriad complex phenomena and events that impact on, and/or act within, the coastal region in a sense and at a scale that threatens the sustainability and well-being of human beings in a given coastal setting. Consequently, it is possible to envision the interplay of a multiplicity of coastal vulnerability pre-cursors and indicators. These indicators can be either physical attributes or social factors.

However, like sustainable development, the true meaning and implications of coastal vulnerability are to be found in integrating the physical conditions within a socio-economic context. Clearly, for practical and management purposes, coastal vulnerability must be people-centred, irrespective of the intensity of the driving processes or causative agents.

In literature, phenomena such as floods, erosion, pollution, sea-level rise and seismo-tectonic events have typically been used as indicators of coastal environmental hazard.^{1,2,3,4,5,6} However, a paradigm shift is needed to integrate multi-phenomena events in coastal vulnerability assessments. Groundwater quality holds much promise in this respect and hence is the focus of this report.

Current literature deals extensively with the exploitation of and dependence on groundwater as a source of potable water in coastal regions of the world.^{7,8} However, of growing concern is the deteriorating quality of groundwater as a result of intrinsic and extrinsic factors related to its occurrence and exploitation.^{9,10} A notable external factor is climate change-induced sea-level rise, which is a major driver of coastal aquifer salinisation on a geologic time scale.

Also disturbing is the discharge (wilful or accidental) of untreated domestic and industrial waste and effluent into the environment within reach of coastal transport processes, as these discharges may ultimately leach or intrude into coastal aquifers. At a regional scale, marine pollution due to offshore crude oil spillage and ship discharge is of concern. This is because ocean currents can transport the pollutants

across national boundaries to landfall at coastal regions far remote from the source of the discharge.

Coastal Zone Profile of Nigeria

The Nigerian coast is about 800 km long (Figure 12.1) and has a coastal zone area that covers some 32 000 km², which represents 30 per cent of national land surface area. The human population in the littoral states of Nigeria based (partly) on data presented by the Centre for Population and Environmental Development (CEPD)¹¹ for the Niger Delta region is about 23.5 million.

Excluding the upland areas of the Niger Delta region littoral states and extending estimates to the coastal area of Lagos State, Nigeria's coastal zone population is in excess of 16 million. This estimate translates to a population density of 500 people/km², which is three times higher than the national average of 160 people/km².



Figure 12.1: Nigerian coastline showing groundwater monitoring stations (imagery from Google Earth).

The major cities within 60 km of the coastline are Lagos, Warri, Port Harcourt and Calabar, and these are interspersed by the major industrial communities of Forcados, Escravos, Brass, Bonny and Ibeno-Eket.

The coastal climate is essentially humid, with the rainy season typically occurring from April to November, but with a short break in around August. In the more hinterland coastal cities of Calabar and Port Harcourt, 20 to 40 mm rainfall attains a monthly peak frequency of occurrence in July and September/October (>20 per cent), while in the case of oceanfront-proximal locations such as Ibeno-Eket, no month showed a peak frequency of occurrence.¹²

With the exception of the absence of a rocky coast segment, the Nigerian coast is morphologically and socio-culturally a microcosm of the Gulf of Guinea coastal states in depicting barrier-lagoon, deltaic, strand-plain beach and coastal swamp physiography with coastline deposits ranging from mud to coarse sand types.

The coastal topography is typically low-lying (<3 m above mean sea level), with some 20 major estuaries and a complex network of tidal creeks on beach-backed swamps in the Niger Delta region. Tides are semi-diurnal, with the mean tidal range increasing eastward from about 1 m, in the barrier-lagoon coast at the extreme western segment around Lagos, to about 2.6 m, around Calabar on the easternmost coastal segment (Figure 12.1).

As a consequence of burgeoning activities in the coastal zone (due to rural transformation and development efforts of various governments and industries as well as development partner initiatives), the population in the littoral states of the Niger Delta region will be about 31.5 million in 2020, based on the projections of the CEPD.¹³ However, for the real coastal zone dwellers (within the influence of tides), the population is estimated to increase to about 22 million by 2020.

The above projections place a burden on the already challenging issue of easy access to potable water in the coastal zone. Many coastal inhabitants are increasingly turning to groundwater exploitation to meet their domestic water needs, with the consequence that groundwater vending has become a booming business.

The rate of groundwater exploitation in the coastal zone has increased phenomenally within the last decade. With no less than two to five boreholes/10 km² in each coastal city (based on field experience), it is estimated that some five million coastal zone dwellers in Nigeria depend on groundwater for daily domestic and other uses.

Groundwater Monitoring

As part of a groundwater-ocean interaction project instituted by the National Centre for Marine Geosciences of the Nigerian Geological Survey Agency in 2007/2008, groundwater static levels and quality parameters were periodically observed, quasi-synoptically, from a total of six research monitoring boreholes spread along the Nigerian coastal region (Figure 12.1). The boreholes are all in the range of 64 to

70 m deep and are located in different morpho-sedimentary and tidal settings of the coastal zone.

The borehole settings and distances from the ocean front are as follows: Victoria Island (0.5 km) is on a microtidal barrier-lagoon setting while Igbokoda (24 km) is on a microtidal transgressive mud coast setting. Warri (60 km) is on a mesotidal deltaic flank setting, whereas Ogbia (65 km) is on a mesotidal upper deltaic setting. Ibeno (4 km) is on a mesotidal lower strand-plain setting while Anantigha (46 km) is on a mesotidal estuarine swamp setting. The corresponding mean static water levels are 163, 105, 202, 395, 132 and 46 cm above ground level.

Details of groundwater monitoring and evaluation are given in a number of reports of the ongoing project.^{14,15,16,17}

Essentially, observations were made over tidal cycles, tidal stages, tidal phases and seasonally. A wide range of water quality parameters was also obtained in addition to static water level dynamic patterns. Most of the water quality parameters, such as pH, conductivity and colour, were determined initially in situ with portable water quality kits before samples were transported to various laboratories (University of Calabar and Cross River State University of Technology) for further periodic analyses at room temperature. Total hydrocarbon concentration and microbial analyses were carried out on the water samples in the laboratory within 24 hours of collection.

Results that are pertinent to understanding coastal vulnerability in a coherent sense are discussed below.

Groundwater Static-level Dynamics

In line with expectations, the tide-averaged groundwater static levels, as exemplified by those of Anantigha (Figure 12.2), show a general shallow-up trend, with the onset of precipitation from 11 April to 12 August 2012, although in a fluctuating pattern. The fluctuating pattern is in response to lunar tidal forcing, in which the peaks coincide with neap tides. Given similar environmental conditions, groundwater surface contamination through leachates will be more pronounced during the rainy or wet season.

A critical evaluation of existing data from the Anantigha monitoring borehole shows that the static water level actually responds to open sea tidal forcing, as evidenced by its consistent daily sinusoidal pattern (Figure 12.3) over the period 22 April to 19 May 2011. Similar sinusoidal patterns of groundwater static level changes are documented from other study locations but with different oscillation amplitudes.^{18,19,20}

As the location of the Anantigha borehole is about 46 km from the ocean front, the pattern shown in Figure 12.3 could result from periodic recharge either from adjacent tidal rivers and creeks or directly from seawater intrusion as a consequence of the landward-sloping hydraulic head with rising tide. Either way, the immediate

implication is that pollutants dissolved in the ocean water can be mixed with the groundwater and so deteriorate its quality.

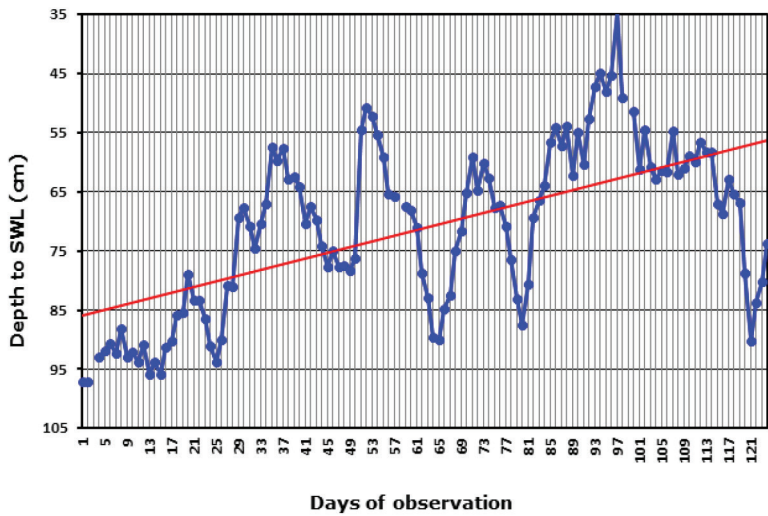


Figure 12.2: Time-series (124 days: 11 April to 12 August 2012) variation in tide cycle-averaged depth to static water level (SWL) of Anantigha groundwater.

Figures 12.4 and 12.5 respectively show that the groundwater level oscillation and time of occurrence of high water are synchronous with that of the adjoining Calabar River, thus re-enforcing the view that the groundwater and river can both be receptacles of pollutants from the ocean.

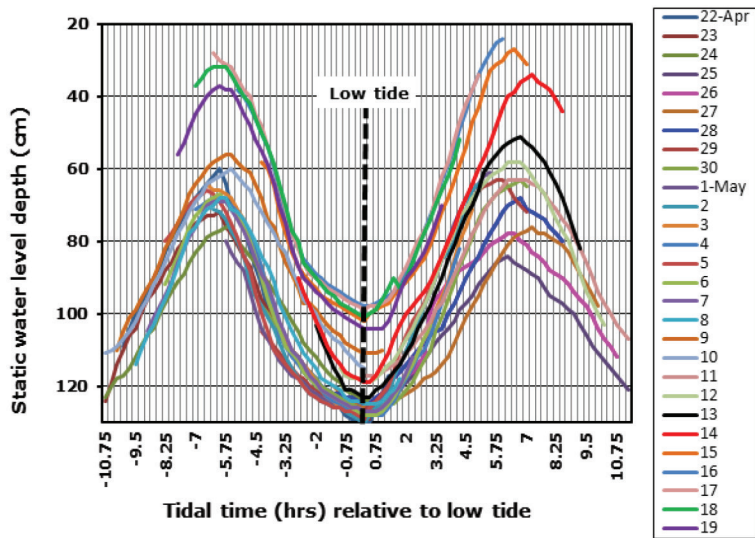


Figure 12.3: Tidal cycle variation in Anantigha groundwater static level (22 April to 19 May 2011).

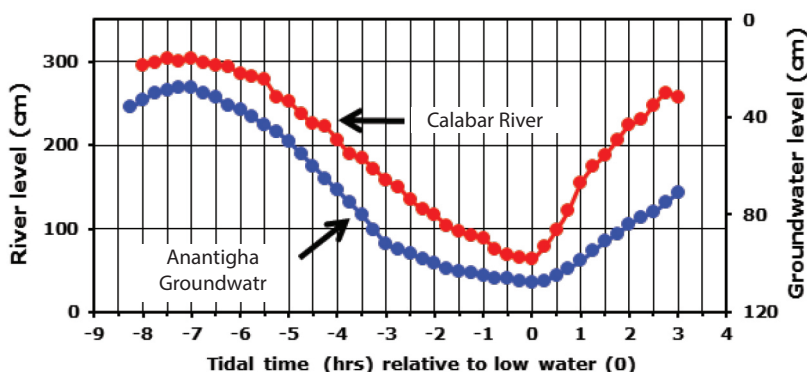


Figure 12.4: Tidal cycle oscillation in Anantigha groundwater and the Calabar River on 4 November 2009, showing a synchronous pattern.

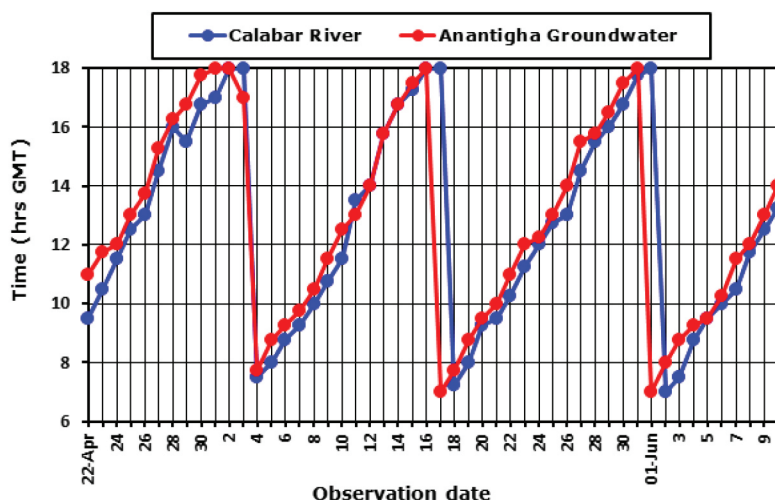


Figure 12.5: Daily times of occurrence of high water in Anantigha groundwater and the Calabar River between 22 April and 10 June 2011 showing a synchronous pattern.

Tidal Excursion Indicators

Conductivity

A confirmatory indicator of seawater intrusion into the coastal aquifers studied comes from monitoring the hydro-geochemical parameters of the groundwater over tidal cycles and tidal stages. This presupposes that ocean water chemistry is markedly different from the chemistry of freshwater. Consequently, the sinusoidal pattern depicted by open ocean tidal elevation followed by hydraulic head-induced horizontal motion should be correspondingly reflected in the concentration pattern of the water quality parameters of the groundwater over a tidal cycle.

Simultaneous monitoring of groundwater conductivity of the westernmost (Victoria Island) and easternmost (Anantigha) boreholes (as depicted in Figure 12.6 for 21 December 2010) shows that there is indeed a similarity in that both readings show a sinusoidal variation pattern of conductivity. Higher concentration values for Victoria Island groundwater are due to its proximity (<0.5 km) to the ocean front.

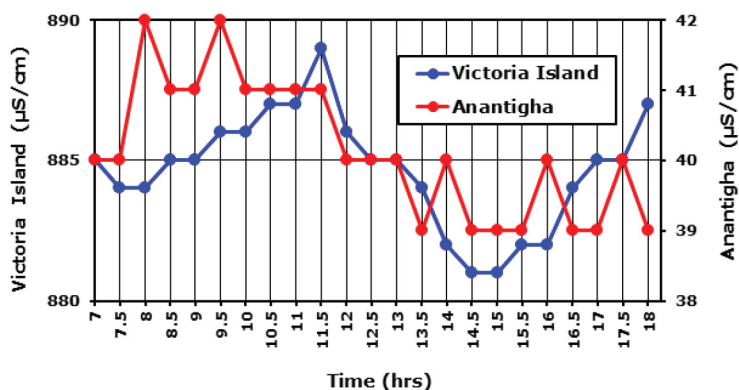


Figure 12.6: Sinusoidal variation in groundwater surface conductivity over a tidal cycle of 21 December 2010 for Victoria Island and Anantigha.

The observed sinusoidal variation in surface conductivity over a tidal cycle of Victoria Island and Anantigha groundwater is further evident in the depth-averaged (surface and 1, 2, 3, 4, 5 m below) conductivity values for groundwater of Warri and Ogbia (Figure 12.7). These values were recorded at locations 60 km and 65 km from the ocean front.

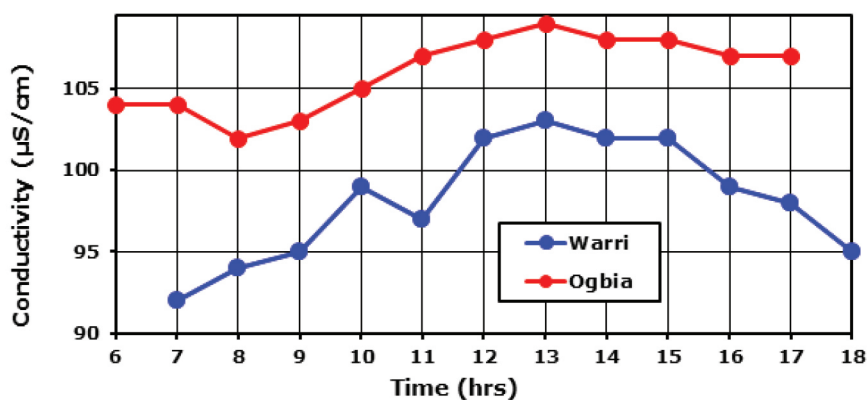


Figure 12.7: Tidal cycle variation in depth-averaged conductivity of Warri and Ogbia groundwater on 25 August 2011, showing a sinusoidal pattern.

As regards the source of the groundwater conductivity variation, the result from the transgressive mud coast of Igbokoda (Figure 12.8) suggests that the Igbokoda River

(located < 1 km from the borehole) is unlikely to be the source. This is because the conductivity of the groundwater is about 100 times higher than that of the river.

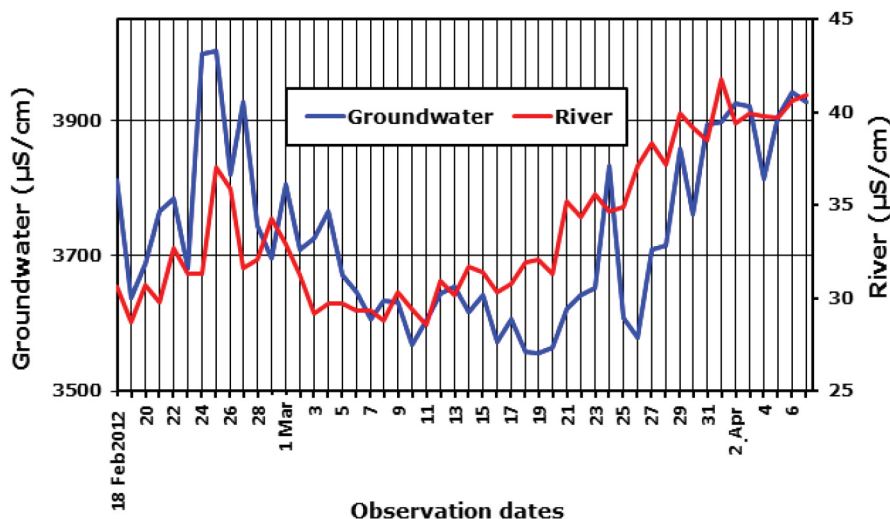


Figure 12.8: Daily variation in tidal cycle-mean surface conductivity of Igbokoda groundwater and river between 18 February and 7 April 2012.

Iodide and total hydrocarbon concentration (THC)

A close examination of high- and low-water stage concentrations of iodide in Victoria Island groundwater over an annual interval (Figure 12.9) shows generally elevated values at high water, which suggests intrusion of seawater, as this water quality parameter is more enriched in the ocean than in fresh water.

Further noted is the ease of groundwater to contamination during the wet season, as exemplified by total hydrocarbons in Warri groundwater (Figure 12.10), where the concentrations in the 16 to 28 mg/l range are over 40 times higher than the dry season counterpart. This seasonal disparity may be a consequence of the shallower static water level during the wet season, hence closer contact with existing hydrocarbon-enriched loads on the land surface. It is also plausible that overland flows and run-offs associated with high precipitation may concentrate high hydrocarbons that ultimately percolate through into the aquifer.

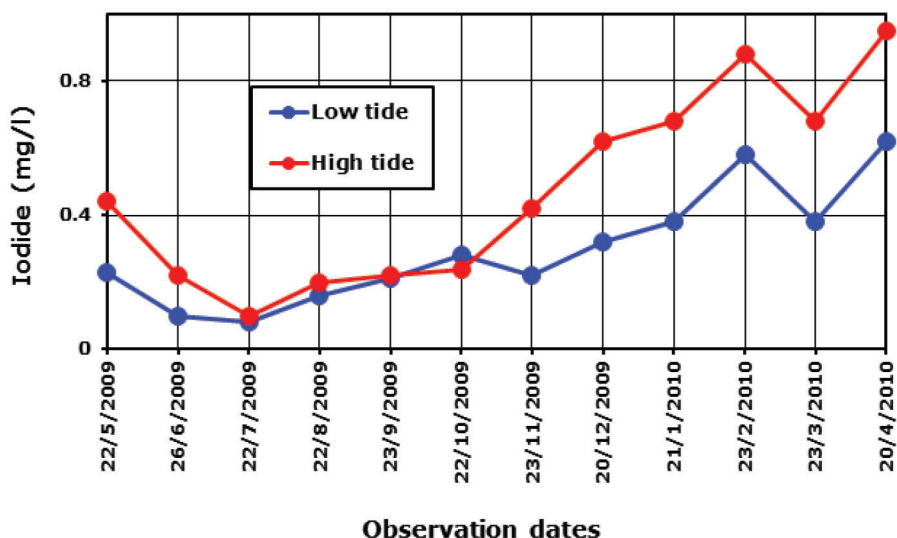


Figure 12.9: Time series variation in iodide concentration in Victoria Island ground-water surface at low and high tide during the period of 22 May 2009 – 20 April 2010.

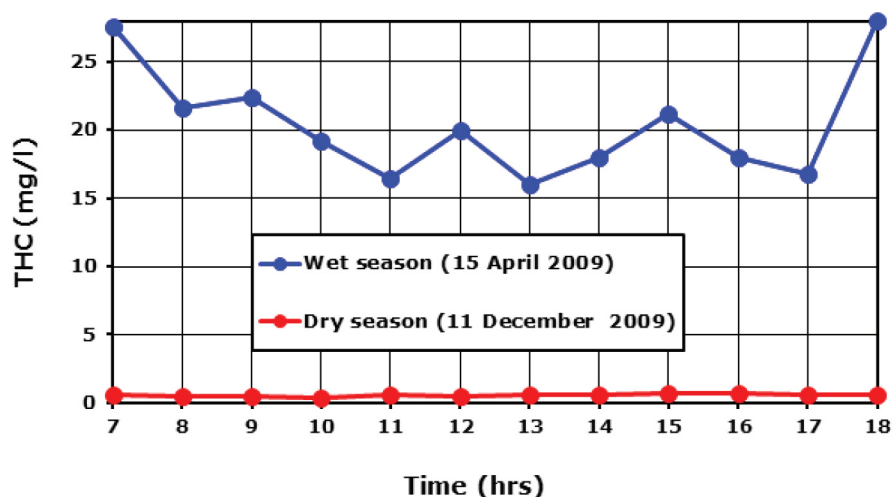


Figure 12.10: Tidal cycle variation in total hydrocarbon concentration (THC) in Warri groundwater during the wet season (15 April 2009) and dry season (11 December 2009).

Water colour

Perhaps the most visible vulnerable groundwater quality is its colour. While most standard guidelines prescribe a permissible limit for colour in the range of 0 to 15 pcu (platinum-cobalt unit) for drinking purposes,^{21,22} tidal cycle results from the studied groundwater (Figure 12.11) for Anantigha, Ibeno and Ogbia rarely attained this value. Anantigha groundwater was, however, the most potable, with values

ranging from 0 to 24 pcu. For the annual study (Figure 12.12), Warri groundwater was closest to being potable, with values ranging from 0 to 31 pcu. The exceptionally high colour values of Igbokoda groundwater may relate, in large part, to location within a transgressive mud coast, but also to a high rate of iron oxidation.

pH value

An important water quality that has relevance to health conditions, is the pH value. The results which are presented in Figure 12.13, show that Igbokoda groundwater is extremely acidic, while the Victoria Island groundwater is very alkaline and thus out of the generally prescribed range of 6.5 to 8.5 for drinking.²³ The high pH values of Victoria Island groundwater is a direct effect of ocean water intrusion, given its proximity (< 1 km) to the coastline.

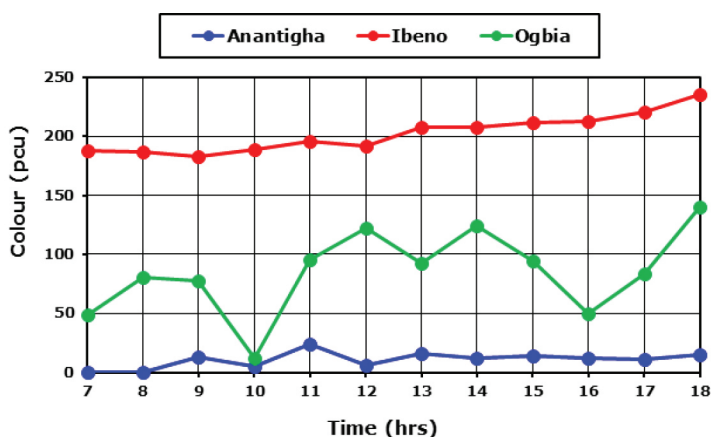


Figure 12.11: Tidal cycle variation in the colour of the surface groundwater of Anantigha, Ibeno and Ogbia on 13 December 2008.

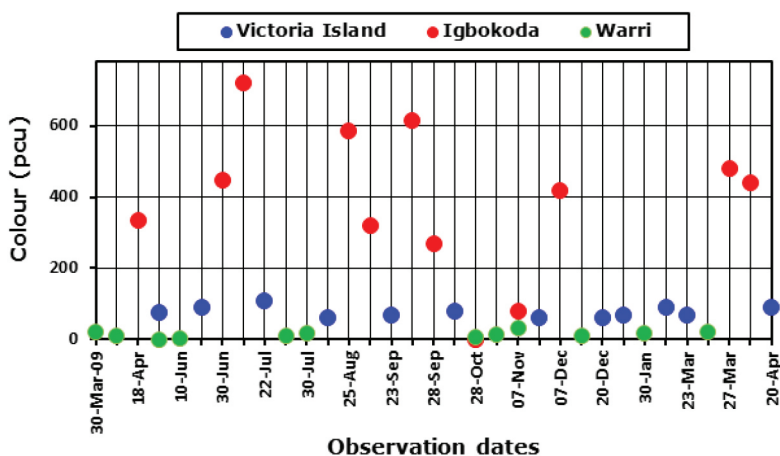


Figure 12.12: Variation in colour at high groundwater static level over time (30 March 2009 – 20 April 2010) for Victoria Island, Igbokoda and Warri.

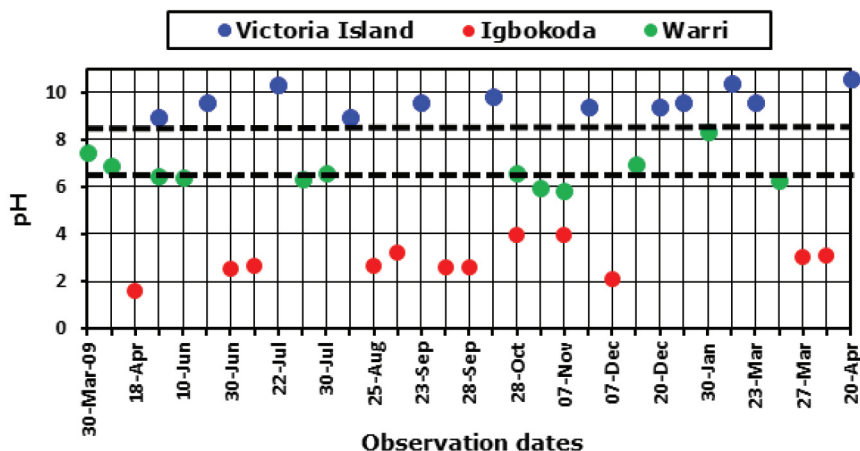


Figure 12.13: Variation in pH at high groundwater static level over time (30 March 2009 to 20 April 2010) for Victoria Island, Igbokoda and Warri. The dashed horizontal lines define the prescribed pH value range for drinking water.²⁴

Interesting, however, is the tendency towards elevated pH values of Anantigha groundwater as the tide rises over a tidal cycle during the dry season (Figure 12.14). In contrast, during the wet season, pH is largely uniform in value and consistently acidic, which may reflect increased infiltration of acidic leachates and/or the effect of the shallower static water level coming into contact with acidic contaminants on or close to the surface.

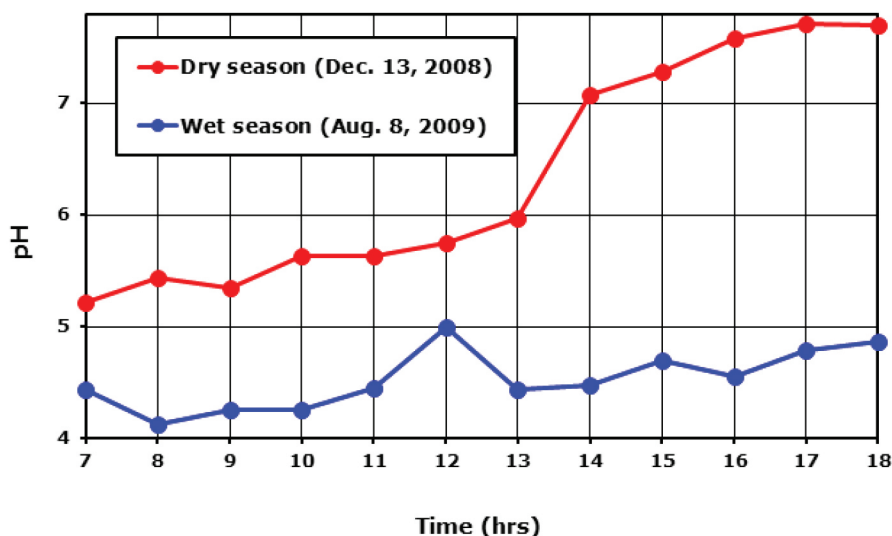


Figure 12.14: Tidal cycle variations in pH of Anantigha groundwater surface during the dry season (13 December 2008) and wet season (8 August 2009). Note that low tide was at about 12h30 during the dry season observation.

Microbial load

Groundwater health quality is most strictly defined by its microbial load. Total coliform count is a commonly cited microbial parameter. A zero value total coliform count is prescribed for drinking purpose by World Health Organization (WHO) guidelines.²⁵ The result shown in Figure 12.15, based on a dry season survey, indicates that the groundwater at Anantigha, Ibeno and Ogbia is unfit for consumption as most total coliform count values exceed 10 cfu/100 ml (dashed line in Figure 12.15), which indicates faecal pollution.

These results reflect unhygienic land use practices in the monitoring vicinity. Apart from localised contamination, flow-related microbial load dispersal can also contribute to the overall load level, as Figures 12.16 and 12.17 show. Essentially, groundwater at high tide commonly show up to 50 to 200 per cent higher total bacterial and coliform counts than at low tide.

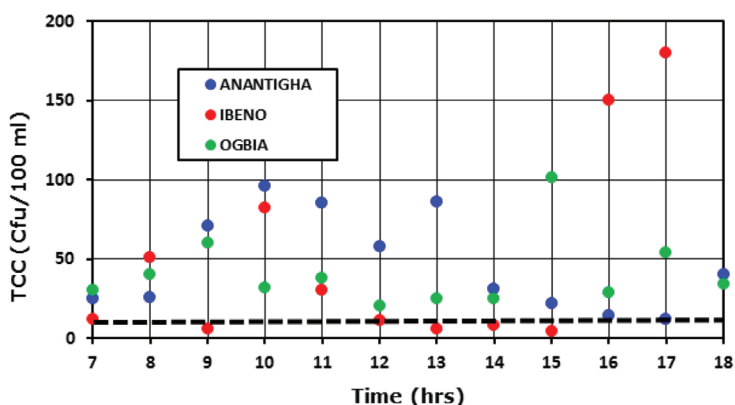


Figure 12.15: Total coliform count (TCC) in the groundwater of Anantigha, Ibeno and Ogbia over a tidal cycle on 13 December 2008.

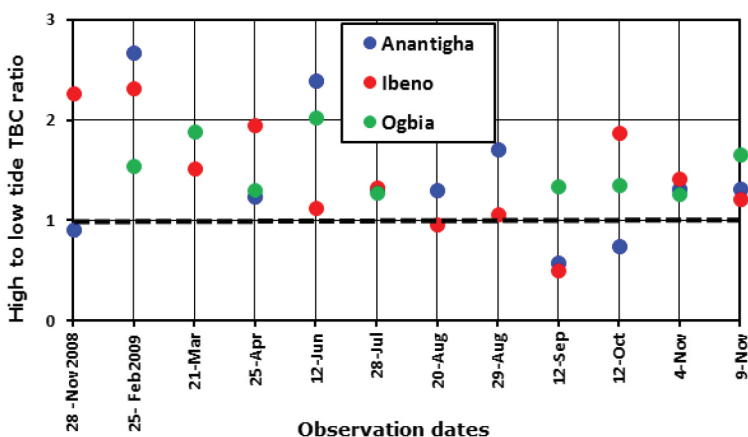


Figure 12.16: High tide to low tide TBC ratio in the groundwater of Anantigha, Ibeno and Ogbia over time.

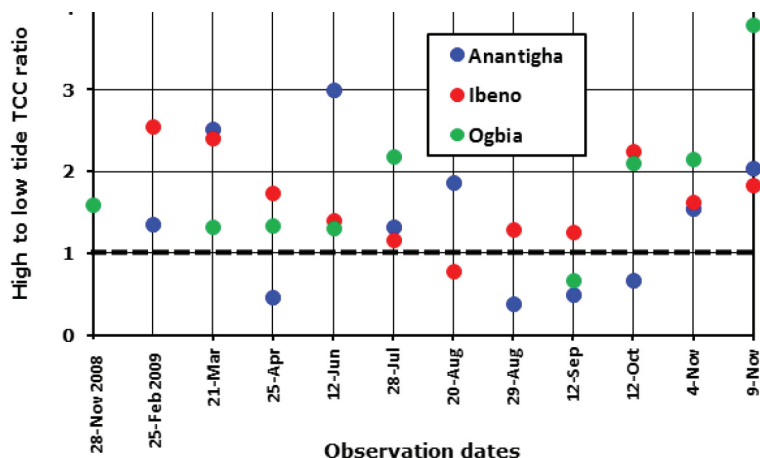


Figure 12.17: High tide to low tide TCC ratio in the groundwater of Anantigha, Ibena and Ogbia over time.

Longevity of Groundwater Quality

In view of the growing patronage of groundwater vendors and the number of overhead tanks that are routinely built for groundwater storage, it was necessary to examine the 'life span' of groundwater abstracted from the study areas.

Tidal phase and stage monitoring of concentration of hydrocarbon-utilising bacteria (HUB) in the groundwater (Figure 12.18) shows instantaneous values of abstracted groundwater at the high water (HW) stage vary from 25 cfu/ml for Warri to 44 cfu/ml for Anantigha groundwater. The occurrence of HUB in the first instance is a pointer to anthropogenic discharge of hydrocarbons into the environment.

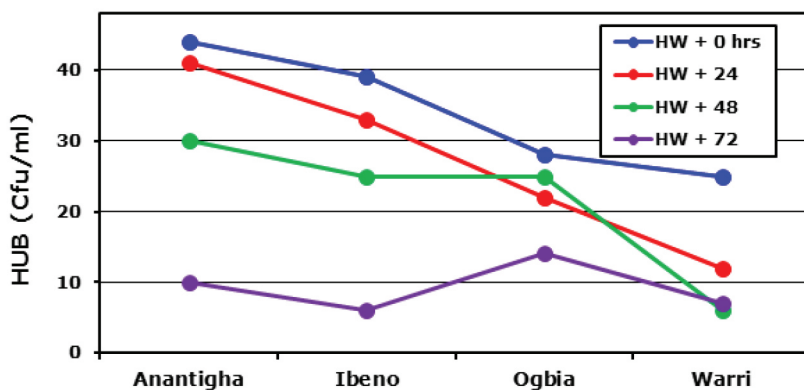


Figure 12.18: Daily variation in post-high tide stage (HW + 0 hrs on 31 August 2011) total HUB count in the groundwater of Anantigha, Ibena, Ogbia and Warri over a three-day interval.

Fortunately, the concentration of HUB in the initially abstracted groundwater gradually decreased daily at all locations, probably as a result of depletion in hydrocarbon concentration as recorded in Figure 12.19.

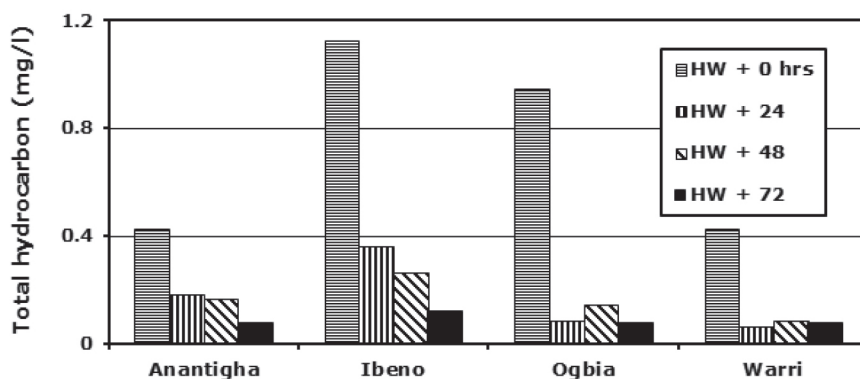


Figure 12.19: Daily variation in post-high tide stage (HW + 0 hrs on 31 August 2011) total hydrocarbon concentration in the groundwater of Anantigha, Ibeno, Ogbia and Warri over a three-day interval.

Quite unfortunate is the fact that, while some categories of microbes such as HUBs diminished in untreated abstracted groundwater over time, other notable human health-impacting varieties increased. Examples of the latter are *Streptococcus faecalis* in Ibeno groundwater, from 3 per cent to 14 per cent (Figure 12.20), *Shigella dysenteriae* in Ogbia groundwater, from 23 per cent to 72 per cent (Figure 12.21), *Salmonella typhi* in Warri groundwater, from 2 per cent to 15 per cent (Figure 12.22), and *Escherichia coli* in Igbokoda groundwater, from 14 per cent to 31 per cent (Figure 12.23).

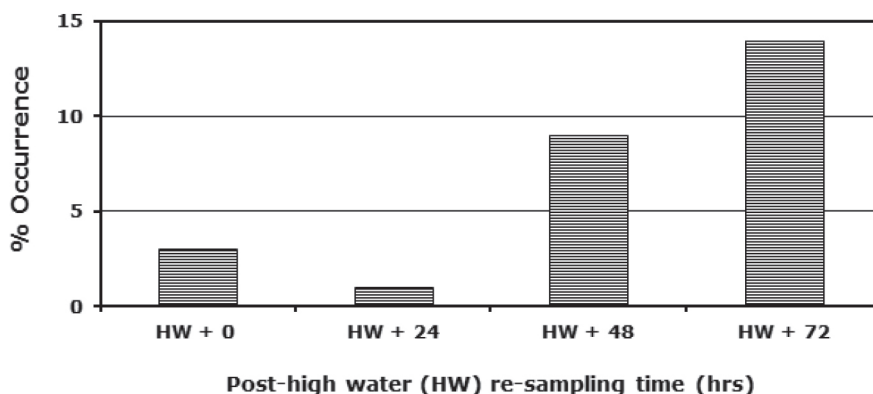


Figure 12.20: Occurrence of *Streptococcus faecalis* in abstracted Ibeno groundwater at high tide stage on 31 August 2011 (HW + 0) and daily variation over a three-day interval.

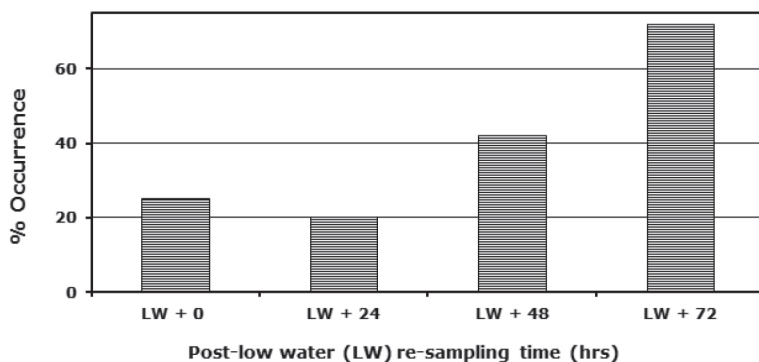


Figure 12.21: Occurrence of *Shigella dysenteriae* in abstracted Ogbia groundwater at low tide stage on 22 August 2011 (LW + 0) and daily variation over a three-day interval.

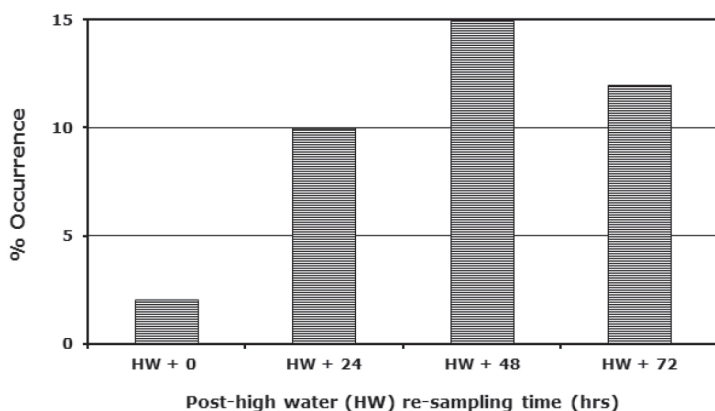


Figure 12.22: Occurrence of *Salmonella typhi* in abstracted Warri groundwater at high tide stage on 30 August 2011 (HW + 0) and daily variation over a three-day interval.

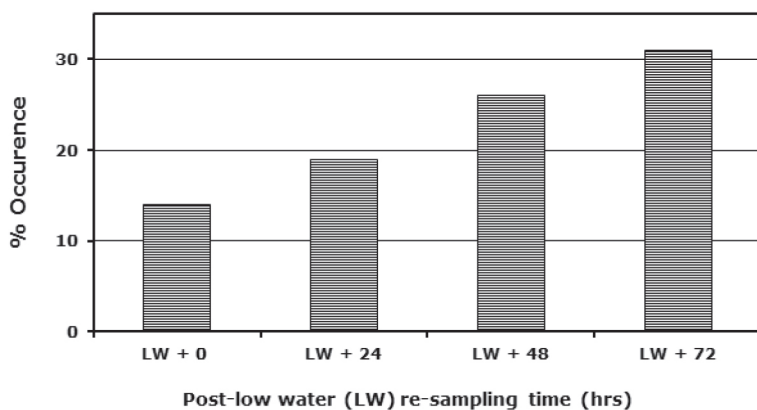


Figure 12.23: Occurrence of *Escherichia coli* in abstracted Igbokoda groundwater at low tide stage on 27 September 2011 (LW + 0) and daily variation over a three-day interval.

Consistent with microbial load changes in untreated groundwater, other water quality parameters (such as pH and colour) showed a deteriorating pattern over time. For instance, the pH of abstracted Warri groundwater after 48 hours dropped by 0.25 to 0.4 pH unit (Figure 12.24), while the pH of Igbokoda groundwater dropped by as much as 0.6 to 0.8 pH unit (Figure 12.25). The pH change over time in the case of Igbokoda groundwater constitutes a health hazard, as the groundwater is very acidic. The tidal cycle mean pH after 48 hours is 2.8 compared to 3.5 on first abstraction.

With respect to water colour, Warri groundwater was observed to vary from <10 pcu on abstraction to over 60 pcu after 11 days of storage under room temperature (Figure 12.26). By contrast, Igbokoda groundwater appears to be stable within the 300 to 500 pcu range over a 4-day interval (Figure 12.27). Clearly, on the basis of the existing drinking water quality standard, the abstracted groundwater is not recommended for consumption without treatment.

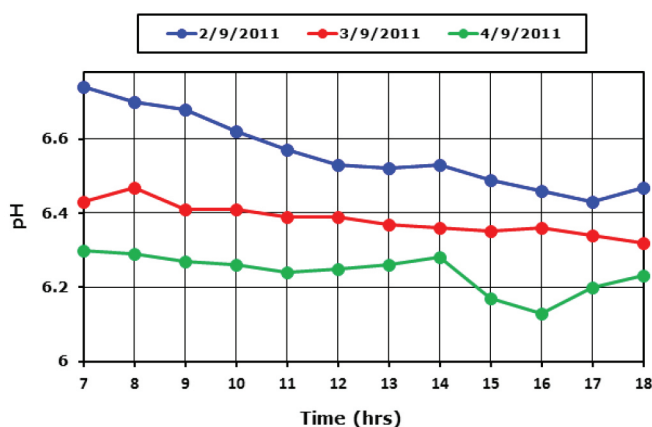


Figure 12.24: Post-abstraction changes in tidal cycle pH of Warri groundwater over a three-day interval.

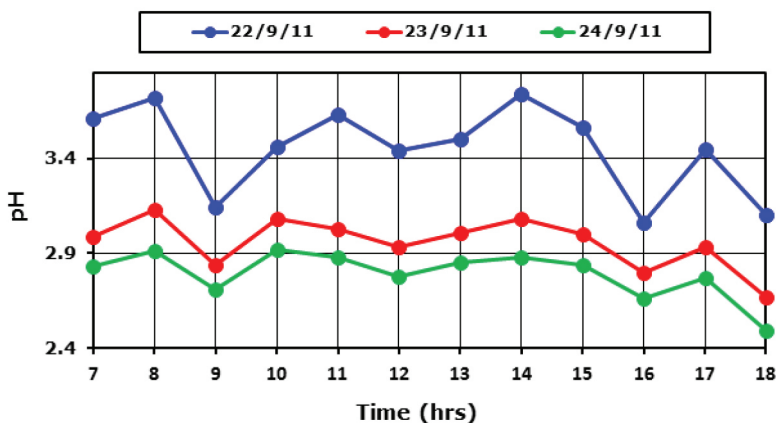


Figure 12.25: Post-abstraction changes in the tidal cycle pH of Igbokoda groundwater over a three-day interval

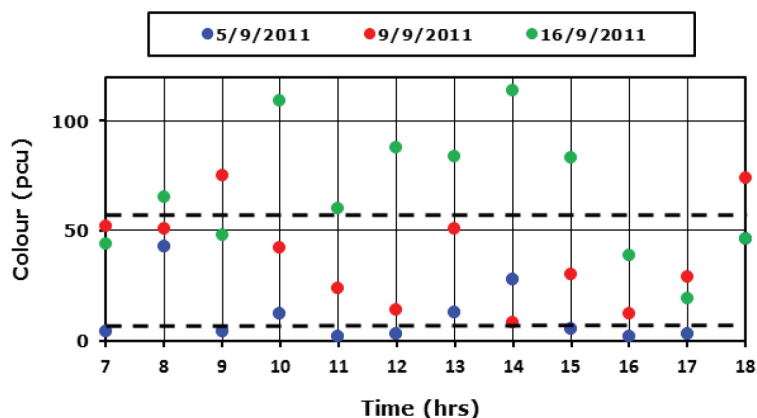


Figure 12.26: Post-abstraction changes in the tidal cycle colour of Warri groundwater over time.

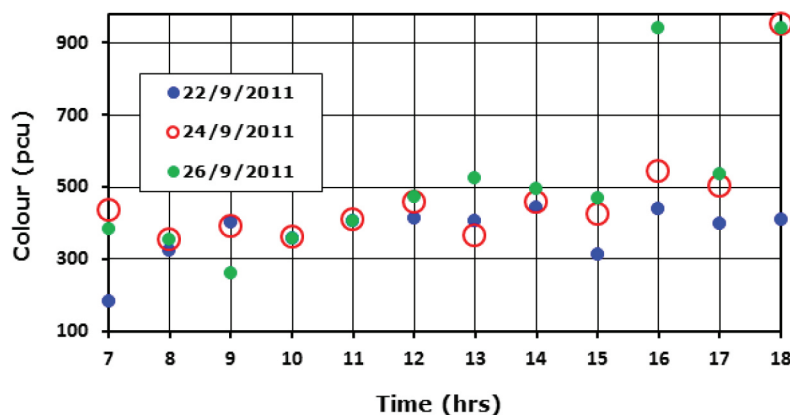


Figure 12.27: Post-abstraction changes in the tidal cycle colour of Igbokoda groundwater over time.

Conclusion

Groundwater quality in the coastal region has the potential for defining trends in a wide range of coastal vulnerability-inducing conditions, both natural and anthropogenic. Most importantly, it holds good promise for integrating physical and social elements of vulnerability that are desirable for coastal hazard contingency and management planning.

Presented results from the Nigerian coastal zone show, when using tidal oscillation as a surrogate, the adverse salinisation effects of sea-level rise on groundwater in coastal aquifers. The quality of coastal groundwater is deteriorating on a human time scale as a result of environmental pollution of various sorts, which have been initiated by humans and dispersed by natural coastal processes. Coastal groundwater

quality vulnerability is notably enhanced by the shallowness of the water table, typically in the 30 to 300 cm range, and by the high groundwater consumer population, which is estimated at about five million people daily within the coastal zone.

A robust ranking scheme of groundwater vulnerability will, in addition to the aforementioned, require information on tidal and seasonal variability in critical water quality parameters, aquifer flushing potential and post-abstraction water quality changes.

Emerging from this study is that groundwater quality in the vicinity of the monitoring stations is unfit for direct human consumption. The spatial representativeness of some aspects of these results, mainly the anthropogenic impacts, defines the direction of future investigation. However, it is important that consumers be sensitised to the need to embrace water treatment guidelines, while local authorities should exert stricter control on waste disposal and effluent discharge into the coastal environment.

At sub-regional levels, issues of cooperation regarding monitoring of and information sharing on transboundary pollutant transport require refocusing. The Nigerian coastal zone is the most down drift in the West African sub-region, being straddled by the eastward-flowing Guinea Current. Consequently, Nigeria's offshore and ultimately nearshore are major receptacles of marine pollution in the sub-region.

Finally, the outcome of this study should find application in many of the states of the sub-region, given the similarities in their human development, physiographic and oceanographic attributes.

Acknowledgements

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CHAPTER 13

Coastal Hazards in Africa

Bhanooduth Lalljee

Introduction

Africa has moved from being an underdeveloped continent to a rising giant, with extensive natural resources. Several African countries have shown a high gross domestic product (GDP) growth rate over the past five years. Economic growth in Africa has been accompanied by a large number of modern infrastructural development projects in coastal regions on the mainland and in the Small Island Developing States (SIDS).

Coastal sub-Saharan Africa has a large expanse of productive land in the coastal zone, but many of these areas are environmentally sensitive zones and fragile ecosystems, which include estuaries, mangroves, coral reefs, raised beaches, coral atolls and deltas. These ecosystems play an important role in maintaining the environment. They are also economic sectors in many countries and generate a large amount of foreign exchange from tourism, fisheries and other associated activities. Coastal zones are prime locations very much in demand by the affluent sections of society and in many countries, such as Mauritius and South Africa (Cape Town), and coastal cities, such as Alexandria, they attract a large amount of foreign direct investment (FDI), especially for international hotels and other tourism-related activities. Almost 40 per cent of the population in West Africa is made up of coastal dwellers, and it is expected that the 500 km of coastline between Accra and the Niger delta will become a continuous urban megalopolis of more than 50 million inhabitants by 2020.¹ By 2015, three coastal megacities of at least 8 million inhabitants will be located in Africa.^{2,3,4}

One of the major threats to continued economic development in Africa is natural and man-made disasters. A disaster is a serious disruption of the functioning of a society, causing widespread human, property or environmental losses that exceed the ability of the affected society to cope with only its own resources.⁵ Over the last four decades, sub-Saharan Africa has experienced more than 1 000 disasters, and the number of disasters reported in Africa has increased significantly since the 1970s.⁶ The economic impact of disasters on countries is becoming increasingly apparent, and it is imperative that the risk of such disasters is reduced and managed,

since even one major disaster can significantly set back and stunt a nation's economic growth. Sub-Saharan Africa is particularly prone to serious human, economic and environmental losses that arise from natural disasters, mainly because its populations and economies are vulnerable and have few resources and low coping capacities. Furthermore, insufficient finance is a major handicap in adapting and mitigating these natural events.

Coastal ecosystems are environmentally sensitive and fragile and are susceptible to the vagaries of weather and a changing climate. It is therefore imperative to ensure that any development takes place in a sustainable manner with due regard to the carrying capacity of the ecosystem and keeping in mind climate variability and climate change. Africa's history abounds with extreme hydro-meteorological events, which are highly likely to be aggravated by climate change.

Droughts and floods are the two most disastrous types of events to affect the largest number of people in continental Africa, with cyclones mainly affecting coastal and island nations such as Mozambique, Madagascar, Mauritius and the Comoros. Low-lying coastal areas, especially in the SIDS, are particularly vulnerable to sea-level rise, coastal erosion and storm surges. Some islands, such as Agalega, may completely disappear from the map.

Climate change is expected to increase the magnitude and frequency of these extreme weather events. Changes in rainfall patterns due to climate variability and climate change have serious implications for the productivity of rain-fed agriculture, on which the economy of most African countries is based.

The coastal area is defined as the interface or transition zone, specifically that part of the land affected by its proximity to the sea and that part of the ocean affected by its proximity to land, and the area in which processes that depend on the interaction of land and sea are most intense.⁷ Sometimes the boundaries between the areas are not fixed as they change with the tides, moon cycles, seasons and high water levels, among other things.

Coastal areas are subject to a number of natural hazards (such as cyclones, tsunamis, tidal waves, storm surges, sea-level rise, earthquakes, coastal erosion, coastal flooding, seawater intrusion and El Niño and La Niña phenomena) and man-made/man-induced hazards (such as destruction of wetlands and other environmentally sensitive areas, excessive development beyond the carrying capacity of the ecosystem, construction of roads and hotels, and industrial, residential and agricultural activities).

Coastal areas are affected by three types of natural disasters. These hazards are of meteorological, geological and biological origin. Those of meteorological origin include floods, droughts, cyclones, sand storms and lightning strikes, which cause fires. Natural processes such as El Niño and La Niña can cause disasters such as floods and long drought spells.

Hazards of geological origin are earthquakes, volcanoes and landslides. Earthquakes under the sea usually result in tsunamis, which can cause havoc in coastal zones, as happened in the Indian Ocean in 2004. Geological hazards are often followed or compounded by other hazards, such as soil erosion, river flooding, coastal inundation, and storm and tidal surges.

Biological hazards take the form of disease epidemics and epizootics, such as malaria, the proliferation of pests and parasites, and invasion by insects.

Very frequently these disasters follow each other or are a combination of two or all three of these processes; for instance, the El Niño weather pattern of 1997/98 caused severe floods in equatorial eastern Africa (northern Tanzania, Kenya, Uganda and parts of Ethiopia) and was followed by a La Niña phenomenon (1999-2000), which led to one of the longest and severest droughts to be associated with this phenomenon in the history of the sub-region. These natural disasters affect the civilian population either directly or indirectly, for example through famine or the outbreak of diseases such as cholera, which directly affect the population, or indirectly by destroying agricultural land, road and communication networks and infrastructure.

This chapter explains the geological and hydro-meteorological hazards that affect coastal regions.

Status

Twenty-two countries form part of the coastal region of the African continent. These countries are found in the Indian Ocean, Atlantic Ocean, and Mediterranean Sea. These include the SIDS: Mauritius, Seychelles, Comoros and the large island of Madagascar.

The population of Africa, which currently stands at 650 million, is expected to grow annually by 30 per cent. The density of people living on the coasts is predicted to double by 2025, increasing from 200 inhabitants/km² to about 500 inhabitants/km². The ensuing pressure on the coastal ecosystem, in all likelihood, will increase several fold. Property in African coastal cities for residential, hotel and other development is among the most highly priced in the world and is very much in demand in most countries. Furthermore, the tourism sector continues to be concentrated in coastal zones, with increasing demand for coastal and sea-based activities. The beaches, the ports and other coastal areas are very important for the economies of most countries and for border protection. In the SIDS in particular, they represent a key and lucrative pillar of the economy since they bring in revenue from tourism and high FDI, as well as foreign know-how and technology. They also generate employment.

All this activity puts further pressure on the coastal areas. Coastal regions of several countries in Africa, such as Senegal, The Gambia, Liberia, Sierra Leone, Nigeria and Cameroon, as well as the SIDS, such as Mauritius, Seychelles and the Comoros, have low-lying lagoons and coastal zones, which are affected by sea-level rise.

The coastal and marine ecosystems in Africa are rich in biodiversity, with many unique species of aquatic plants and animals. Coastal zones include lagoonal systems, mangroves, swamps, marshes, wetlands and estuaries, while marine ecosystems include coral reefs and seaweed/seagrass forests. Coral reefs take thousands, if not millions, of years to develop and represent an important and special feature of marine ecosystems. Mangrove forests are another key feature of coastal systems. It is important to preserve the aquatic habitat and its biological functions in order to ensure the survival and protection of this rich and unique plant and animal biodiversity, which includes many endemic and threatened species.

Coastal Hazards

The following hydro-meteorological and geological hazards are the most significant and destructive natural events to affect coastal areas: cyclones, torrential rains, coastal flooding, sea-level rise, tsunamis, droughts, dust storms, earthquakes, coastal erosion and coastal landslides.

For a coastal hazard risk to occur, there must be a 'driver' and a 'receptor'. The driver may be a natural hazard such as an earthquake or cyclone or tsunami and the receptor is normally coastal infrastructure with or without human beings. There must also be a pathway for the hazards to occur. Examples of pathways are flooding, overtopping and overwashing. Many of the coastal hazards have a number of drivers and a number of receptors, which act alone temporally or spatially or which synergise each other. The consequences of these drivers and receptors acting through pathways include economic damage and loss, human casualties, and land and other environmental degradation.

Coastal vulnerability is the ability of a nation to withstand or mitigate the consequences of a coastal hazard. Because of the high infrastructural development in coastal zones, the vulnerability of these areas to coastal hazards is ever increasing. Some of these infrastructural developments have crossed the carrying capacity of the ecosystem and make the ecosystem highly vulnerable to any further events. This vulnerability can be seen in cities such as Alexandria, Port Louis, Cape Town and Casablanca. The havoc caused by the March 2013 flood in Port Louis, and which led to the death of scores of people, was mainly due to infrastructural development, which caused soil sealing and reduced the absorption capacity of the drains to carry the flood water.

Meteorological Hazards

Cyclones and storm surges

Tropical cyclones, also known as 'hurricanes' in the North Atlantic and 'typhoons' in the North Pacific, are intense low-pressure atmospheric systems. These systems

are well organised and have circular wind patterns, with winds circulating around the centre of the cyclone. Known as the 'eye', the centre is usually a relatively small and calm zone of low pressure, referred to as the 'Central Pressure Index' (CPI), which gives an indication of the wind speed. The lower the CPI, the more intense the wind and the stronger the wind flows. The eye is surrounded by the eyewall, where the highest surface winds occur.

Tropical cyclones start their lives as depressions, which derive their energy from the upper ocean heat. They need sea surface temperatures of at least 26-27°C and suitable atmospheric and oceanic conditions to develop. As they move inland they lose this energy and disintegrate. The wind rotation around the low pressure zone depends on the geographical location. Above the equator, the wind rotates anticlockwise whereas below the equator the wind rotates clockwise. Wind speeds can reach over 300 km/hr in super cyclones. A cyclone (named Haiyan) that hit the Philippines in 2013 had winds of about 380 km/hr, which was the highest wind speed in recorded history. Since landfall of the cyclone takes place on coastal and adjoining areas, the brunt of the impact is first felt in these sensitive areas. Impacts include damage to agriculture and food supplies, infrastructure, roads, electric and telephone poles and lines, residences and, at times, loss of human lives. Cyclone Haiyan almost destroyed the entire city of Tacloban in the Philippines, killed about 3 000 people, with thousands more reported missing, and caused several billion dollars' worth of damage to the economy.

Cyclones are regular meteorological features of SIDS in the Indian Ocean and of Madagascar and the east coast of Mozambique. Cyclones are formed every year, normally during the period November to April, and bring considerable havoc to these countries, which results in millions of dollars of infrastructural damage and loss of human life.



Figure 13.1: Cyclone Guito in the Mozambique channel (February 2014)

On the other hand, many of these countries depend on the rains associated with these cyclones for their water supply. The rainwater recharges underground aquifers and fills reservoirs, on which the population depends for the rest of the year.

Cyclones cause high waves and storm surges, which arise following a rapid rise in the sea water surface level produced by the strong cyclonic winds. The low pressure associated with the system lifts up the sea surface and the cyclonic winds push forward a very large amount of water upfront its eye onto coastal zones, causing destruction. Such surges can cause damage to coastal infrastructure, destruction of beaches and coastal (beach and cliff) erosion, and can destroy sand dunes, coral reefs, sea grass beds, and mangrove forests. . This swell is amplified as the system comes closer to the coast and makes landfall. Storm surges are also caused by extra-tropical cyclones and cut-off lows (a closed low pressure system that rotates clockwise and can generate strong winds and intense rainfall) that do not move off quickly enough (Figure 13.2). The storm surge that occurred in Durban and the coast of KwaZulu-Natal in March 2007 was the result of a cut-off low that occurred 700 km out to sea. The highest wave recorded was 12 m, measured off Richards Bay.



Figure 13.2: A storm surge

The consequences of a tropical storm or cyclone are damage to infrastructure, forests, livestock, agriculture, people and to a nation's economy in general.

Some of the other effects of cyclones include total stripping of sand from beaches, leaving stony and rocky outcrops and ledges exposed; movement of large quantities of beach sand inland to be deposited on coastal highways, in swimming pools and on beachfront properties; movement of large quantities of beach sand offshore, resulting in siltation and shallowing of the water depth; disappearance of sand dunes, resulting in vertical seaward slopes that are bereft of vegetation; and movement of all the sand to one end of a beach in small bays. Beach erosion and damage to

coastal roads, tourist hotels and amenities, and infrastructure can have a significant, negative impact on the economy of the country. Although hotels and bungalows can put in place mitigation measures, such as high walls, large areas of the coastal belt are inhabited by squatters and poor people. Storm surges are particularly destructive to this section of the population.

The heavy rainfall associated with the cyclonic systems causes coastal and inland flooding. Sea water flows onto the land and causes further damage, through its effects on the salinity of soil, beach erosion, and the destruction of coastal infrastructure. The increased soil salinity that results from seawater intrusion has a negative impact on agricultural productivity, and it can take the soil many decades to recover its original health and fertility. Furthermore, water from flooding and inundation can remain stagnant in depressions and pockets in the land and can contribute to health problems through, for example, proliferation of water-borne and vector-borne diseases such as cholera, typhoid, malaria, chikungunya and dengue fever.

Given their low level of preparedness and relatively weak ability to withstand such weather extremes, developing countries and SIDS are particularly vulnerable to the impacts of such disasters. Climate change is predicted to bring more intense, and therefore more devastating, cyclones. Records from the Republic of Mauritius show that although the frequency of cyclones hitting this island nation has reduced in recent years, the intensity of those cyclones that do has increased significantly.

The intensity of cyclones has been observed to be increasing, with gusts reaching over 300 km/hr. Figure 13.3 below shows the trend of increasing intensity of the cyclones that hit the island of Mauritius.

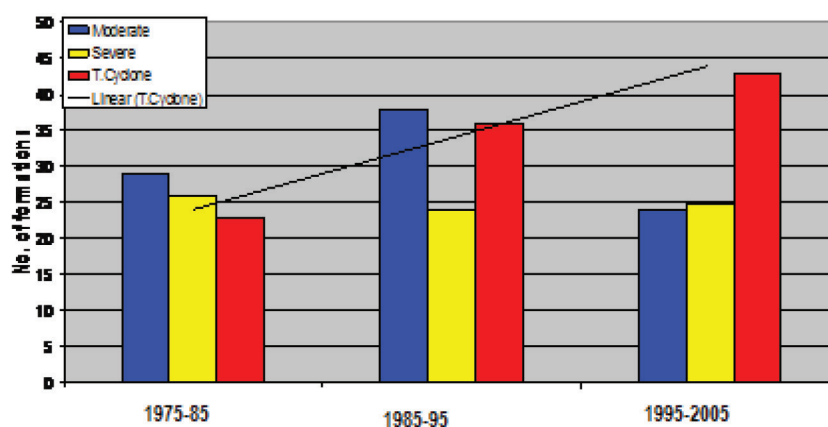


Figure 13.3: Cyclone intensity trend in Mauritius

Coastal flooding

Coastal flooding and flash floods are temporary events that can occur due to torrential rains, storm surges and the heavy rainfall associated with cyclones.

Countries vulnerable to flooding normally have inadequate or constricted drainage systems. Drains are usually blocked because of mismanagement or by solid waste. Deforestation, silting of river beds and soil erosion add to the problem. Low-lying coastal areas are more vulnerable than the highlands. Coastal cultivation and soil fertility are particularly vulnerable to coastal flooding, which may not only destroy crops but also wash off fertile topsoil, making the soil infertile and unproductive. It takes decades of care before the soil can regain its original fertility. This phenomenon is a regular feature of some of the coastal regions of the island of Mauritius.

Sea-level rise

Sea-level rise is a permanent increase in the level of the sea at the coast at any given point and is attributed mainly to global warming. The increase in the Earth's temperature is causing melting of the polar ice caps, which, in turn, is increasing the volume of water in the oceans. The volumetric expansion of the water column due to the increase in temperature also adds to the rise in sea levels. The higher temperatures lead to an increase in the sea surface water level. Both these phenomena result in a rise of the sea level in many places, by varying amounts. The sea level is predicted to rise further. This will have disastrous impacts on cities along coastlines mainly because of the high concentration of people but also because economically important activities, such as those related to tourism and ports, will be negatively affected. Climate change scenarios predict that by 2080, three of the five regions at risk of flooding in the coastal and deltaic areas of the world will be located in Africa: North Africa, West Africa and southern Africa.⁸

In the Gulf of Guinea, sea-level rise could induce overtopping and even destruction of the low barrier beaches that limit the coastal lagoons, while changes in precipitation could affect the discharges of the rivers that feed them. These changes would have an impact on lagoonal fisheries and aquaculture. Changes in the location, frequency and intensity of cyclones in the Indian Ocean region could threaten island nations, while East African coasts could be affected by changes in the frequency and intensity of ENSO events and coral bleaching.⁹ Coastal agriculture (e.g. plantations of palm oil and coconuts in Benin and Côte d'Ivoire, and shallots in Ghana) could be at risk from inundation and soil salinisation. A 1 m sea-level rise in Kenya could lose the country almost US\$500 million just from the three crops of mangoes, cashew nuts and coconuts.¹⁰ In Massawa, one of Eritrea's two port cities, a 1 m rise in sea level is estimated to cause damage of over US\$250 million as a result of the submergence of infrastructure and other installations infrastructures such as telephone and electricity lines that are important to the economy.¹¹

Geological Hazards

Coastal landslides

Landslides are very common in hilly coastal areas. The unstable soil on the slopes is loosened by heavy rains and moves down the slopes towards the sea. All infrastructure on the slopes is destroyed and generally pushed into the water. This extraneous foreign matter, along with the large amounts of soil and sediment, causes water cloudiness and heavy silting in the water, cuts off sunlight from penetrating the lower depths of the water, and reduces dissolved oxygen in the water, resulting in the smothering of aquatic plants and animals and large-scale biological instability. Mangroves, fish, crabs and other coastal dwelling plants and animals that prefer clear, oxygen-rich water and sunlight are negatively affected, and this can lead to their death and decay. This, in turn, further reduces the dissolved oxygen and sunlight penetration and destabilises the coastal and marine ecosystems.

The causes of landslides may be of geological, morphological, physical, human-induced or seismic origin, but the trigger is most often heavy or torrential rains falling in these sensitive areas, which loosens the soil and starts the landslide. In Mozambique, for example, causes of landslides include heavy rainfall of short duration, high declivity SLOPES of the Mount Tumbine geological soil and intense cultivation, which result in the removal of natural vegetation that holds soil aggregates together and thereby prevents soil from moving downwards or reduces the amount that does.

The occurrence of coastal landslides is likely to increase in the wake of climate change due to changes in the intensity of precipitation, further exacerbated by the increasing number of buildings on hill slopes adjoining the sea.

Coastal erosion

Natural calamities such as cyclones and storms are accompanied by strong winds and swells, which cause extensive and rapid coastline destruction. Coastal erosion can leave people homeless and leave less land to develop or preserve for. This phenomenon has increased over the past several years, making it a major coastal hazard.

Coastal erosion of sandy beaches can leave tree roots exposed and weaken the trees, which can topple over during a cyclone, causing infrastructural and other material damage. Fallen trees also give an unpleasing appearance to the beach.

Dust storms

A dust storm is a meteorological phenomenon that is particularly prevalent in arid and semi-arid regions and along the western coast of Africa. This phenomenon occurs when gusts blow loose sand from a dry surface, the particles of which are transported over long distances. These gusts can transport large volumes of sand,



Figure 13.4: Beach erosion in Mauritius

with the leading edge composed of a dust wall of up to 2 km in height. Dust storms cause loss of soil and organic matter from dry lands, making the soil infertile. Young plants are affected by the abrasive effect of dust storms; the storms also reduce visibility, which affects aircraft and road transportation, and cause respiratory and other health problems. All of these can affect the health of the economy and human habitation, and natural ecosystems.

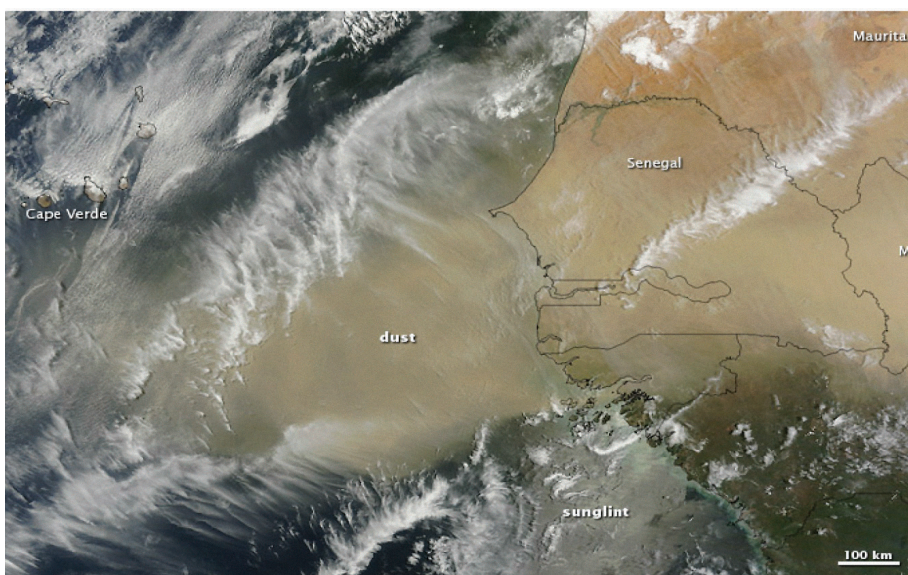


Figure 13.5: Dust storm extending from Mali to Cape Verde¹²

A massive plume of thick dust blew off the west coast of Africa on 29 April 2012, extending from Mali to Cape Verde, and was captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite¹¹ (Figure 13.5). Sand seas and drying marsh sediments provided plentiful material for this dust storm.

Earthquakes

An earthquake is a sudden motion of the earth that is caused by an abrupt release of slowly accumulating stress. Undersea earthquakes generate tsunamis.

Earthquakes are described in detail in Chapter 2.

Tsunamis

The term 'tsunami' refers to a series of travelling ocean waves of extremely long wavelength that results in an enormous volume of water landing on a coast with incredible force. A tsunami is quite different from a storm surge or from what is commonly called a 'tidal wave' by the non-scientific community. In a storm surge it is the surface water that moves landward, while in a tsunami the whole mass of water moves upwards and towards the land. Tsunamis are generated by a number of geological events: earthquakes in the seafloor, which lift and move a large mass of water; submarine landslides that occur below or near the ocean floor; underwater volcanic eruptions; underwater explosions; the collapse of a caldera; erosion and landslide of a large coastal cliff into the water; or the impact of a meteorite on the ocean floor. The term 'tsunami' is of Japanese origin and means 'harbour war', which attests to the force of a tsunami and its destructive power. The waves generated by a tsunami depend on the mechanism that generates the tsunami, the geographical location, the distance of the targets from the point of origin of the tsunami, and the coastal and marine topography and bathymetry, among other things.

Waves generated by tsunamis have wavelengths (distance between two same points on adjacent waves) that vary between several km and 400 km. This is in sharp contrast to ordinary waves, whose wavelengths vary from 10 to 40 m. When tsunami waves make landfall, they may reach heights of 10 m or more. Enclosing structures such as harbours or small bays tend to amplify these waves further.

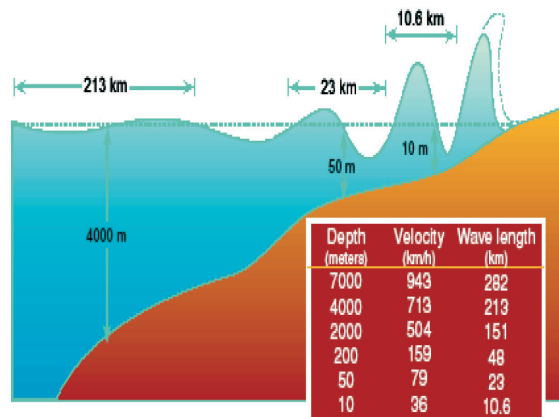


Figure 13.6: Enhancement of a tsunami wave¹³

Tsunami waves usually reach low heights in the open sea, but these waves become taller and taller as they approach the coast and sometimes reach up to 30 m in height. As the tsunami wave makes landfall, it destroys everything in its path. Tsunami damage is a direct result of inundation, wave impact on structures and coastal erosion. Tsunami waves move at speeds of greater than 500 km/hr.

Tsunami victims are mostly coastal inhabitants. Although tsunamis are not new occurrences, the tsunamis that hit Indonesia in 2004 and Japan in 2011 sensitised people about these catastrophic phenomena and made 'tsunami' a household word. The Band Aceh (Indonesia) tsunami, which killed over 160 000 people and destroyed property worth billions of US dollars, led to the creation of a number of tsunami early warning systems being put in place in many coastal countries. Governments met and adopted the Hyogo Declaration in Kobe, Japan at the World Conference on Disaster Reduction, which set the Framework for Action for 2005-2015 (Box 1). The objective of the Framework was to build resilience to disaster among signatory nations. The Framework is linked to the millennium development goals (MDGs) and to the UNESCO-led Decade of Education for Sustainable Development (2005-2014).



Figure 13.7: The two stages of a tsunami¹⁴

The earthquake that triggered the Japanese tsunami resulted in waves of up to 40 m in height, which travelled 10 km inland. It led to 16 000 deaths and about 3 000 people missing. The tsunami also resulted in damage to the three nuclear reactors at Fukushima.

The earthquake, which was the most powerful ever to have hit Japan, is also reported to have shifted the earth on its axis by about 10-25 cm, and brought the northeastern portion of Japan closer to North America by about 2.4 m.

In the Pacific Ocean and the Indian Ocean, early warning systems for tsunamis have been put in place to provide warnings to countries in these regions.



Figure 13.8: Infrastructural damage from the tsunami in Japan¹⁵

Droughts

Droughts are long periods of moisture deficits, which affect soil moisture, crops, livestock and humans. They result from a reduction in rainfall over a long time. When rainfall becomes relatively scant or infrequent, it can disrupt the normal balance between precipitation and the evaporation-transpiration process and drought can begin. Droughts can have devastating effects on human lives, crops and livestock, and constitute one of the most dreaded natural hazards in Africa.



Figure 13.9: Drought in Kenya due to the La Niña effect¹⁶

Lack of adequate water for drinking and sanitation leads to malnutrition, thirst and disease outbreaks among humans and animals; crops and livestock can die due to drought. Hydro-electric power dams dry up, which disrupts industrial activities. The human and economic losses and costs caused by environmental degradation mount up rapidly and it can take years to recover. For a more in-depth reading on drought, please refer to Chapter 8.

Management of Natural Coastal Hazards

Management of natural coastal hazards involves putting in place adequate and efficient adaptation and mitigation strategies well in advance of the potential event.

Adaptation Strategies

Box 1. The Five Hyogo Framework for Action Commitments (2005-2015)¹⁷

1. Make disaster reduction a priority.
2. Governments should integrate disaster risk reduction into their laws, programmes and plans, and ensure the participation of local communities in planning.
3. Know the risks and take action.
4. Countries should define and understand potential risks so that they can develop early warning systems adapted to the needs of each community.
5. Build understanding and awareness.
6. Governments should provide information, include disaster reduction in formal and informal education, and ensure that invaluable local knowledge about disaster risks is preserved and transmitted.
7. Reduce risk.
8. Countries should apply safety codes to ensure that schools, hospitals, homes and other buildings do not collapse in earthquakes; avoid siting communities in hazard-prone areas such as flood plains; and protect forests, wetlands and reefs that act as a natural barrier to storms and flooding.
9. Be prepared and ready to act.
10. Governments and regional or local authorities should conduct risk assessments, adopt contingency plans, test preparedness by such measures as evacuation drills and ensure emergency services, response agencies, policy makers and development organisations are coordinated.

The Hyogo Framework for Action (HFA) is the primary global framework for disaster risk reduction and management. Together with the United Nations International Strategy for Disaster Reduction (UNISDR), the African Union (AU) and numerous other development partners, the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) are key partners in supporting its implementation. The World Bank's disaster risk management (DRM) activities in sub-Saharan Africa are coordinated by the Africa DRM team.

The best way to confront natural disasters is to create a culture of safety among the communities at risk and to enhance the capacity of the people living in vulnerable areas. Preparedness is key in helping communities manage the inevitable disasters when they do occur. This can be achieved only by having a cross-sectoral approach in putting up early warning systems and building the capacity of the national institutions responsible for data collection, analysis and issuance of forecasts and warnings of the disasters. Any sustainable management of disasters in the coastal areas will require the integration of climate information in all aspects of planning.

The key functional components of early warning systems for hydro-meteorological hazards include risk assessment, vulnerability analysis, hazard detection and prediction, communication and dissemination of knowledge, public awareness, coordination and post-disaster support.

A sound risk assessment process is fundamental for ensuring that coastal hazards, and the effect that climate change has on coastal hazards, are appropriately taken into account in local government policy, planning and resource consent decision making.¹⁸ The process has the advantage of being conducive to building in the sensitivity of outcomes to different levels of uncertainties in climate change drivers. To implement effective approaches to managing a coastal hazard risk, such a risk must first be appraised through¹⁹:

- Identifying the coastal margins and describing the associated assets located there that are at risk from coastal erosion, storm and tsunami inundation;
- Considering how such a risk may be induced or exacerbated by climate change or by changing development in coastal margins; and
- Evaluating the likelihood and consequences of such a risk over the timeframes of interest.

This process allows the climate change risks and subsequent adaptive responses to be prioritised and compared equitably with other risks, resource availability and cost issues (including works) that governments and authorities face.²⁰

Preparedness also involves zoning of the land-use practices in the coastal areas and proper planning of development in the coastal zones, introduction of government policies to protect vulnerable communities, and evacuation plans to be followed in the event of a disaster happening or a warning of an impending disaster received.²¹

Most African countries already have set up disaster management committees, which are steered at the highest level.

For early warnings to be effective, they must be accurate and must build the confidence of the targeted community. They must also be timely in order to allow sufficient time for the people to prepare for the coming hazard. Furthermore, these warnings must be appropriately and effectively circulated to reach the maximum number of people.

A key aspect of disaster preparedness involves having in place a cross-sectoral multi-hazard approach and coordination between various agencies for the effective management of coastal disasters.

Mitigation Strategies

The purpose of mitigation is to minimise the loss of life, as well as property, material and environmental damage due to natural coastal disasters. Mitigation can include structural options, beach nourishment, natural vegetative options, as well as policies and legislation regarding building and other development.

Structural mitigation has been seen as a solution to eroding beaches and movement of sand through the construction of engineered structures along the coast. However, these structures have proved to be short lived and to provide only an illusion of safety to the public, which results in long-term damage of the coastline. Some examples include the use of groins and gabions, which are a man-made solution to longshore current movements up and down the coast. While these structures are efficient to some extent and for some time, in the long term they simply result in sand buildup further down the beaches. Bulkheads are man-made structures that help protect homes built along the coast and other bodies of water, but they can induce erosion in the long run. Jetties are structures built to protect sand movement into the inlets through which boats for fishing and recreation move.

Nonstructural mitigation includes the use of organic and soft structures for protection against coastal hazards. These structures include artificial dunes to help slow down water movement or to replace eroded dunes. Beach nourishment is another type of nonstructural mitigation used to ensure the survival of beaches. Vegetation is a key factor for erosion protection and for stabilising sand dunes. Batatran is a ground trailing vine that is used in Mauritius to nourish beaches and stabilise beach dunes. Mangroves, in addition to their other benefits (providing a habitat and breeding ground for a large number of aquatic animal species), can help to protect coastlines from storm surges and cyclones.



Figure 13.10: Mangroves on the island of Rodrigues

Conclusion

Coastal plains are environmentally sensitive areas and particularly vulnerable to climate change. These areas are under intense pressure from development, as they are prime areas for tourism, ports and other sectors of the economy. It is important that all governments develop and promote appropriate strategies and action plans for the protection of these coastal regions for the purpose of adapting to the effects of a changing climate and that they develop disaster risk reduction plans for the purpose of protecting the population and infrastructure. Many coastal African countries and SIDS already have their NAPA National adaptation plan of actioned ICZM integrated coastal zone management plans. However, implementation of these plans is still a matter of discussion in several cases.

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CHAPTER 14

Urban Hazards and Vulnerabilities in Sub-Saharan Africa

Mitulo Silengo

Introduction

Currently, Africa is the fastest urbanising continent, with an estimated annual increase in the urban population of 4.87 per cent.¹ Sub-Saharan countries² in particular have experienced a rapid increase in population, with an annual increase in population of 2.5 per cent and a population of 856 million people in 2010.³ In this region, 37 per cent of the total population is classified as urban.⁴ Poverty is still prevalent, with nearly half of its population subsisting on less than US\$1.25 a day.⁵ Human development indicators such as life expectancy at birth, which stands at 56.8⁶ years today, remained constant at 49.5 years between 1990 and 2000, largely due to the impact of the human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) and only improved by 5.5 per cent between 2000 and 2012.⁷

The United Nations Population Fund (UNFPA)⁸ notes that the rapid increase in population has overtaken any economic progress achieved in the recent past, leaving nearly 22 per cent of Africa's people poorer than they were in the mid-1970s. HIV/AIDS has emerged as one of the region's health challenges, with more than 22 million of its population living with HIV/AIDS, 61 per cent of these being women.^{9,10} The sub-region accounts for 67 per cent of all people living with HIV/AIDS globally and 91 per cent of all new infections among children.¹¹ The epidemic is believed to be responsible for more than 14 million orphaned children.¹² As a region, sub-Saharan Africa is also affected by the burden of other diseases, such as malaria.¹³

In Africa, poverty has increasingly become an urban spectacle.¹⁴ The urbanisation process in many countries in the sub-region has not resulted in a reduction of urban poverty. In fact, poverty rates have instead increased, with, in some instances, the rates of poverty being closer to those in rural areas.¹⁵

Disaster risk is normally regarded as a result of interaction between hazards and vulnerability of livelihoods and economies.¹⁶ This may be distinguished from exposure to hazards, which mostly suggests the physical characteristics of vulnerability. In Africa, this exposure is especially pertinent as it involves an increasing

number of people living in unsafe urban areas.¹⁷ The factors behind the growing exposure of sub-Saharan Africa to natural hazards are rapid population growth and urbanisation. Inadequate municipal infrastructure and ineffective urban regulation have worsened, coupled with a lack of urban planning and enforcement of building standards. This scenario makes large parts of the urban population vulnerable to natural hazards.¹⁸ This is commonly the case for the rapidly growing unplanned urban settlements.

The increase in urban dwellers in sub-Saharan Africa in the past two decades has been due to the rural-urban migration of people in search of better prospects in urban areas.¹⁹ In the coming few decades, it is projected that 95 per cent of urban growth will take place in the developing countries of Africa and Asia.²⁰ In sub-Saharan Africa, it is predicted that the population in urban settlements will grow from 324 million (in 2010) to 730 million in 2035.²¹ A substantial proportion of this rapid urban growth will result from unplanned or informal settlements, which will take the form of urban slums. It is also expected that the main causes of urban growth will be the natural expansion of cities, the transformation of rural areas into urban areas and rural-urban migration.²²

As these cities and urban settlements increase in population size, they develop into major hotspots of hazards and become vulnerable to disasters. As already noted, urban areas in developing countries are generally characterised by unplanned informal settlements, where large numbers of unemployed people live in unsafe conditions, which contribute to their vulnerability.²³ Lack of access to essential public amenities, such as safe drinking water and sanitation facilities, and food insecurity are common in these settlements. As the 2011 World Disaster Report (WDR)²⁴ notes, if these urban areas and cities are managed well, they can become more secure places to live in; however, they can also be unsafe for those who live in urban locations where local authority governance is poor or nonexistent. As a result inequalities between the well-planned and resourced urban areas and those on the peripheries of local authority control are usually evident. The WDR 2011 further observes what it calls the 'urban risk divide' as being one of the key challenges that confront humanity today. These underlying risk drivers (of badly planned and managed urban settlements) may be further magnified by climate change-induced hazards, such as flooding and the associated threat of disease epidemics.²⁵

This chapter examines urban hazards and vulnerability in sub-Saharan Africa. It considers urban drivers of disaster risk and opportunities for reducing these drivers and building the resilience of communities in these areas.

Urban Development Trends in Sub-Saharan Africa

Urban settlements are areas with a high population concentration. These areas can be distinguished from suburban and rural areas that have notably lower population

densities and that usually have a lower concentration of economic activity.²⁶ In many African countries, urban areas are defined as localities or centres of administrative and/or commercial significance, usually with the majority of their residents being dependent on non-agricultural activities.²⁷ The designation of an area as urban depends on the national criterion of population numbers that is adopted.^{28,29} This number may range from 1 500 to 10 000 inhabitants.³⁰

Sub-Saharan Africa is experiencing significant demographic changes. As more people migrate to the cities in large numbers, it is projected that Africa will be more urbanised than rural by 2030 and that cities will have to accommodate more than 300 million new urban residents over the next 25 years.³¹ Certain countries in the sub-region are experiencing urban growth rates that exceed four to five per cent per annum.³² The United Nations Human Settlement Programme (UN-HABITAT) observes, for instance, that in 1960, Johannesburg (in South Africa) was the single metropolis in sub-Saharan Africa, with a population over one million people. A decade later, three other cities (Cape Town, Lagos and Kinshasa) had over one million people and by the late 1980s the list comprised four cities in West Africa (Abidjan, Accra, Dakar and Ibadan), four in East Africa (Addis Ababa, Dar es Salaam, Khartoum and Nairobi) and four others in Central-southern Africa (Durban, East Rand, Harare and Luanda).³³ By the year 2010, the sub-region had 33 cities with a population that exceeded one million people.³⁴ As most of the population in sub-Saharan Africa will reside in urban areas over the next 30 years, this demographic transition presents both an opportunity and a challenge.³⁵

Overcrowding, poor housing, underemployment and joblessness, and inadequate public social infrastructure, particularly related to the delivery of essential public facilities, characterise the urban settings in sub-Saharan Africa.³⁶ Whereas urbanisation has resulted in an overall reduction of poverty in other regions of the world, this has not been the experience in Africa. Davis (2004) considers this situation of growing urbanization, notwithstanding slow or poor urban economic progress, as paradoxical.³⁷ He notes that urban areas in Côte d'Ivoire, Tanzania and Gabon, whose economies were shrinking by two to five per cent per annum between 1980 and early 1990s, were yet supporting growing population rates that ranged between five and eight per cent per year. As a consequence of growing urban population rates amid shrinking economies, the urban poor are bound to inhabit unsafe and fragile land, such as hill slopes, riverbanks and flood-prone areas, or to squat near to dangerous industrial complexes or toxic dumps.³⁸

It is evident that the fast-growing towns and cities in sub-Saharan Africa represent a concentration of vulnerable people, as the urban population is frequently found in informal and unplanned settlements. Growing urbanisation is associated with increased risks, as unplanned growth seldom considers physical hazards.³⁹ A joint World Health Organization (WHO) and UN-HABITAT 2010 report,⁴⁰ notes that urbanisation is also linked to economic development. It surmises that populations

in most urbanised countries have higher incomes and that the populations in urban areas are usually better off than those in rural areas. This is because residents of urban areas have better access to social welfare services, such as health and education.

Notwithstanding the opportunities and benefits that cities offer, they have also created glaring inequalities and several forms of social exclusion and marginalisation. For many African city inhabitants, this means living in poverty and squalor, usually in unplanned informal areas with inadequate access to social amenities and urban services.⁴¹ The rapid population growth has, in many cases, overstretched municipal capacity to deliver decent housing, clean potable water and adequate sanitation facilities, which are essential for good living in urban environments.⁴² The result has been unhealthy housing conditions and problems related to poor urban planning.

These problems have significant implications for what the WHO and UN-HABITAT suggest as determinants of health, which include the social, economic and ecological factors that affect the health of the populations.⁴³ In urban environments, the specific determinants of health encompass population characteristics, the type of urban governance in place, the natural and built environment, and the quality of social services offered. In many urban settings, these determinants of health have given rise to a three-way hazard of urban conditions.⁴⁴ This hazard comprises:

- (a) Infectious diseases such as tuberculosis, pneumonia, HIV and diarrhoeal diseases;
- (b) Non-communicable illnesses, especially those associated with lifestyle, such as diabetes, hypertension and heart disease; and
- (c) Injuries that arise from road accidents and those sustained in violent urban crime incidents.

In particular, communicable diseases are major hazards in many urban areas because of the high population concentration and inadequate safe water supply and sanitation facilities. This is coupled with inadequate healthcare services, especially in the poorer peri-urban informal settlements.

The Development of Urban Slums in Sub-Saharan Africa

UN-HABITAT⁴⁵ defines slums as areas where a group of people live who lack access to improved water and sanitation, have no security of tenure of land and whose dwellings are structurally poor and less durable, often with insufficient living space. In 2001, an estimated 71.9 per cent of the residents in urban areas of sub-Saharan Africa were categorised as slum dwellers⁴⁶ (Figure 14.1).

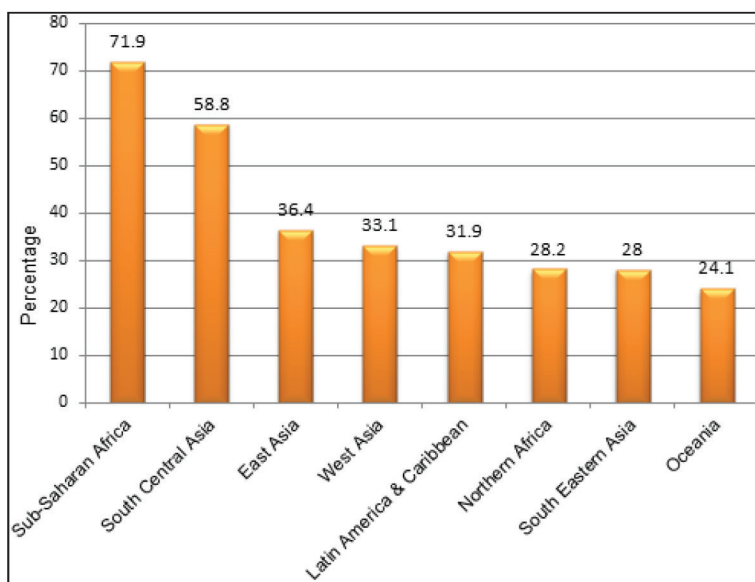


Figure 14.1: Slum dwellers as a proportion of urban population (2003).⁴⁷

This point is further illustrated by the following statistics: an estimated 74 per cent of urban dwellers in Zambia live in slums; similarly over 80 per cent live in slums in Nigeria and Sudan; and over 90 per cent live in slums in Tanzania, Madagascar and Ethiopia.⁴⁸ The higher densities of these areas are illustrated by the Kibera slum in Nairobi, Kenya, where more than half a million people live in an area that comprises only 225 hectares.⁴⁹ These settlements are not only indicators of the economic divide present in urban areas – they also reveal established societal patterns of people settling in areas on the basis of ethnic and religious identity, as seen in the slums in Abidjan and Lagos.⁵⁰ In Ethiopia, where urban poverty is prevalent due to high unemployment and chronic housing scarcity, an estimated 70 per cent of urban dwellers live in slums.⁵¹ For example, Dire Dawa, an Ethiopian city, has, in the past, experienced a damaging flood that killed hundreds and left thousands homeless, due to poor shelters being constructed in high-risk urban areas.⁵² Many of the urban houses have either poor or no proper water and sanitation facilities and solid waste is not collected.

The main factors that contribute to slum development are:⁵³

- Lack of access to sufficient affordable urban land;
- Inadequate affordable and safe housing options; and
- The absence of urban infrastructure and urban services.

These factors can be ascribed to:⁵⁴

- Weak local human and institutional capacity and governance of local authorities, which lead to unplanned settlement growth, frequently in fragile physical

environments, such as on hill slopes, swampland and other hazard-prone areas; and

- Inadequate financial capacity of local authorities due to insufficient budgetary allocation by central governments and/or poor revenue collection due to a limited resource base.

The above factors contribute to the failure of local authorities to fulfil their responsibility of basic service delivery, infrastructure development, and provision of adequate housing and services to communities. These are conditions necessary for promoting social and economic development, and a safe and habitable environment. Thus, urban housing delivery has become one of the main developmental challenges for sub-Saharan countries. For instance, the poor housing delivery systems in sub-Saharan Africa's biggest city, Lagos, have led to widespread development of unplanned or squatter settlements.⁵⁵ It is evident that the gap between supply of and demand for better housing in many urban areas of sub-Saharan Africa has been growing over time.

One of the major features of urban settlements in sub-Saharan Africa is the informal sector economy. This is the major source of income for many people, who earn their living from informal sector businesses found either in or outside slum neighbourhoods.⁵⁶ Although these informal sector businesses are found in the slum areas, their customer base extends to other parts of the city. Generally most slum residents are in low-wage jobs, such as tailoring, cobbling, carpentry, recycling of plastics and scrap metal, and a range of home-based businesses. Many others are employed as security guards, domestic workers, piecework labourers, tinsmiths and self-employed barbers and hairstylists.⁵⁷

The United Nations System has given UN-HABITAT the responsibility of assisting nations in monitoring and attaining the *Cities without Slums* target. This is also known as 'Target 11', which is one of the targets of Goal 7 of the Millennium Development Goals (MDGs). Goal 7 of the MDGs is concerned with promoting environmental sustainability. The aim of Target 11 is to promote the attainment of substantial improvements in the lives of at least 100 million slum residents by the year 2020.⁵⁸

While this slum target is commendable, it is only a part of the general development agenda. The conditions of slum residents in sub-Saharan Africa are only likely to improve if steps are taken to achieve the other MDGs, such as Goal 1, whose main aim is the eradication of poverty and hunger; Goal 4, which is aimed at reducing child mortality; Goal 6, which is aimed at combating HIV/AIDS; and Goal 8, aimed at setting up partnerships for development. Although substantial progress has been made in most areas of the MDGs, a lot more effort is required to meet the set targets.⁵⁹

Drivers of Risk in Urban Areas

The United Nations International Strategy for Disaster Reduction (UNISDR) identifies drivers of risk⁶⁰ in cities and urban areas as:

- Increasing urban inhabitant numbers and concentration of people, putting pressure on land resources and facilities, and growing settlements in low-lying areas, beside unstable slopes and in hazard-prone spaces;
- Centralisation of funds and capability at national level, with inadequate financial and human resources and capacity at local authority level and undefined mandates for disaster risk reduction and response;
- Ineffective local administration and lack of participation by local stakeholders in planning and urban administration;
- Poor management of water resources, drainage systems and solid waste, which result in floods, landslides and disease outbreaks;
- The degradation of environments, due to infrastructure developments, such as road construction, industrial pollution, reclamation of wetlands and unsustainable resource use that compromise ecosystem services, such as flood regulation and protection;
- Deterioration of public infrastructure and unsafe buildings, which may result in buildings collapsing;
- Unorganised emergency services, which reduce the capacity for rapid response and preparedness; and
- Negative impacts of climate change, which is expected to increase or decrease extreme temperatures and precipitation and to result in an increase in the frequency and intensity of floods and other climate-induced disasters.

Urban areas in sub-Saharan Africa have all the conditions described above.⁶¹ The exposure of the urban population to what Wisner et al. refer to as ‘dynamic pressures’ and ‘unsafe conditions’ (in their Pressure and Release model) contributes to the vulnerability of urban populations to disasters.⁶²

Hazards and Vulnerabilities of Urban Settlement

The disaster profile of sub-Saharan Africa is closely related to the vulnerability of its population and national economies. This situation is worsened by the lack of coping capacity. A large proportion of urban residents who live in unplanned settlements that are situated in low-lying zones, such as floodplains or drainage basins, are vulnerable to disasters.⁶³ The UNISDR defines a hazard as any dangerous phenomenon, substance, human activity or circumstance that causes injury, loss of life or destruction of property and livelihoods, and environmental damage.⁶⁴ ‘Vulnerability’ refers to the characteristics and conditions of a community, system or asset that make it prone to the harmful consequences of a hazard.⁶⁵ As indicated in the previous

sections, poverty is a major feature of the urban poor and is the underlying cause of urban vulnerability. The following section highlights some of the vulnerabilities of urban settlements in sub-Saharan Africa.

The Nature of Settlements

As observed earlier, the process of urban growth, especially the concentration of people and property on fragile land, reclaimed swamps or wetlands in developing countries, increases the vulnerability of people.⁶⁶ In particular, poor standards of construction, insufficient water supply and sanitation facilities, poor transport systems, environmental pollution, high unemployment, and high levels of crime characterise many cities.⁶⁷ Turok⁶⁸ notes, for example, that in South Africa almost a quarter of all households live in informal dwellings; that is, nearly 3.4 million households. Inhabitants of these dwellings are more likely to live in overcrowded and poor conditions. These settlements are also more vulnerable to fires, floods and water pollution.⁶⁹

This situation is also characteristic of some informal settlements in Zambia, such as the peri-urban area of Makululu in Kabwe. The majority of the housing stock in this settlement is made of mud bricks without proper foundations (Figure 14.2). This results in buildings collapsing during any heavy downpours of rain, as shown in Figure 14.3.



Figure 14.2: Housing type in Makululu, Kabwe, Zambia. Figure 14.3: Collapsed house in Makululu after rains.

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Lack of Basic Social Services

The inadequate provision of essential public services, such as clean potable water and sanitation facilities, is a major vulnerability for inhabitants of informal peri-urban and slum areas or urban areas in sub-Saharan Africa. In Zambia, for instance, most unplanned areas constitute peri-urban areas with a high population density. Essential municipal services, such as water supply and sewerage systems and solid

waste management, are either insufficient or non-existent, which causes a public health hazard in urban areas.⁷¹ Further, 26.4 per cent of the residents in unplanned settlements do not have access to safe potable water.⁷² As a result, widespread use is made of shallow wells and pit latrines, which are usually sited close to each other. In some cases, the lack of local government service provision has resulted in organisations such as CARE International and World Vision International stepping in to fill the service vacuum with community-led development initiatives; however, these efforts are not sustainable.⁷³

Poor Waste Management

In the Bwaise Parish of Kampala, Uganda, Musoke⁷⁴ found that poor waste management, narrow drainage and unplanned building of structures were responsible for flooding in the area. Illnesses were usually the result of flooding. Water-related diseases, such as malaria, diarrhoea, cholera and typhoid, were commonplace in the area.⁷⁵

In urban areas of Ghana, solid waste disposal systems were also found not to function adequately.⁷⁶ And, where available, these services were overstretched due to pressure from high population densities. The poor delivery of waste management services in informal settlements results in piles of uncollected solid waste.⁷⁷ Similar experiences are shared by the peri-urban settlement of Kanyama in Lusaka, the capital of Zambia (Figure 14.4). The settlement has poor drainage and very poor collection of solid waste, which results in garbage being dumped in open drains, as shown in Figure 14.5. This causes flooding in some areas and the outbreak of water borne diseases.⁷⁸ Cases in point are the flooding episodes of 1977 and 1989 that the settlement experienced.⁷⁹ As a consequence, scavenging and open-air burning of these piles of uncollected solid waste are common sights in many urban areas of Zambia.⁸⁰



Figure 14.4: Uncollected solid waste in Kanyama.

© Mitulo Silengo/DMTC⁸¹



Figure 14.5: Solid waste in open drains in Kanyama, Lusaka.

Urban Disease Burden

The poor in urban areas are also vulnerable to disease because they are exposed to poor health and environmental conditions.⁸² For example, in Zambia the vast majority of households in informal settlements use shallow wells (Figure 14.6) that are dug a few metres from pit latrines. This results in a high frequency of diarrhoeal diseases in the communities, particularly during the rainy season when the latrines overflow and contaminate the wells.⁸³

Cholera outbreaks in peri-urban settlements of the city of Harare are well known.⁸⁴ For example, in late 2008 and early 2009, Zimbabwe had a serious cholera outbreak, with a reported 98 592 cases and 4 288 deaths.⁸⁵ In the Kenyan town of Kisumu, shallow wells provide an important water source in slum settlements, as water tables are high. The high water tables make it difficult to build proper latrines; thus, shallow wells are exposed to threats of contamination by faecal matter, a potential source of health hazards for residents.⁸⁶



Figure 14.6: Drawing water from shallow wells in Makululu, Zambia.

© Adrian Phiri/DMTC⁸⁷

Slum Fires

Slum fires usually occur from the use of candles or kerosene for lighting, and illegal and unsafe electricity connections. Some of the more recent incidents of fire in African cities include the incident in the Mukuru-Sinai slum in Nairobi, which burned down in 2011 following a spillage from an open oil pipeline into a storm-water drainage system.⁸⁸ It is estimated that more than 100 people were killed and more than 100 injured. In Cape Town, a fire displaced 4 000 people in January 2013 in the township of Khayelitsha.⁸⁹ Fire occurrences in the informal settlements of South Africa have in the past claimed between 2 000 and 3 000 homes in a single incident.⁹⁰

Urban Violence

Over the last two decades, the increasingly quick pace of urbanisation in developing nations has also been accompanied by a rise in urban violence. In areas where communal toilets are used, this increases the risk of rape at night and of violence against women, particularly where the facilities are located far from their homes. The consequences of sexual violence against women include injury, unwanted pregnancy and sexually transmitted diseases, including HIV/AIDS. Furthermore, domestic gender-based violence has also worsened and is attributable to poverty and the reliance of women on their men folk.⁹¹ In some countries, this is a result of an increase in the availability of small arms, and alcohol and drug abuse, especially among the unemployed youth.⁹² Recently, xenophobic violence has also been recorded in urban areas of Africa. For example, in South Africa, illegal immigrants have been subjected to intimidation and violence.⁹³ The recurring conflict between locals and immigrants usually relates to perceived competition for livelihood resources.

The rise in urban violence fosters a sense of insecurity in residents and surrounding communities. In some city suburbs, this has given rise to 'gated communities', whose entry is restricted to residents and their invited guests. It is also common to find houses surrounded by high walls, fences and electric fences.

Armed Conflict

Involuntary migration that results from civil conflict also contributes to urbanisation.⁹⁴ The main destinations of refugees or internally displaced persons (IDPs) fleeing conflict are urban areas. In sub-Saharan Africa, armed conflict that involves insurgents, as a result of rebellion, contributes to this migration to urban areas.⁹⁵ Recently, such displacements occurred in Côte d'Ivoire, the Democratic Republic of Congo (DRC), Mali and Somalia, with refugees and IDPs contributing to the increase in urban populations.⁹⁶ The transmission of infectious diseases and an increase in urban crime has been attributed to or associated with such migrants.⁹⁷

Disaster Risk Reduction Initiatives in Urban Areas

In light of the foregoing hazard risks, a number of initiatives have been put forward to reduce risk in urban areas. One such global initiative has been the Hyogo Framework of Action (HFA) (2005-2015), with the theme *Building the Resilience of Nations and Communities to Disasters*. This initiative was agreed on in 2005 during the World Conference on Disaster Reduction, which was held in Kobe, Japan. The HFA recognised that disaster risk was made worse by increasing exposure of people to various hazards associated with unplanned urban growth. The framework outlined five *Priorities for Action*,⁹⁸ to guide the implementation of disaster risk reduction. These were:

- (a) *Making Disaster Risk Reduction a Priority* – this requires prioritising disaster risk reduction at both national and local levels, with strong, organised structures for its implementation;
- (b) *Knowing the Risks and Taking Action* – this includes identifying, assessing and monitoring risks, and enhancing early warning systems;
- (c) *Building Understanding and Awareness* – this involves using information, raising awareness and educating people to promote values of safety and resilience for all;
- (d) *Reducing Risk* – this involves reducing the causal risk factors; and
- (e) *Being Prepared and Ready to Act* – this emphasises disaster preparedness for effective response.

Under the HFA, national governments were expected to⁹⁹:

- Develop national organisational structures;
- Undertake baseline assessments on the state of disaster risk reduction;
- Publish and update summaries of national programmes;
- Review progress made in achieving the objectives and priorities of the Hyogo Framework;
- Use applicable international legal mechanisms; and
- Integrate disaster risk reduction with climate change policies.

The successor framework to the HFA, the Sendai Framework for Disaster Risk Reduction 2015-2030¹⁰⁰ was adopted on 18 March 2015 at the United Nations World Conference on Disaster Risk Reduction in Sendai, Japan. This framework is intended to build on elements that will ensure continuity with the work done by nations and other stakeholders under HFA. The Sendai Framework outlines four priority areas:

Priority 1: Understanding Disaster Risk

Priority 2: Strengthening disaster risk governance to manage disaster risk

Priority 3: Investing in disaster risk reduction for resilience

Priority 4: Enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction.

The Disaster Risk Reduction framework is also aligned with the Sustainable Development Goals (SDGs)¹⁰¹ also adopted in 2015, which outline the post-2015 United Nations development agenda. In particular the following SDGs speak to issues of intended to end poverty, promote inclusive, resilient and sustainable development:

Goal 1. End poverty in all its forms everywhere

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable.

In 2010 the UNISDR launched the *Global Resilient Cities Campaign*. This initiative specifically focuses on building the resilience of cities to cope with natural disasters. The initiative is based on three main guiding principles: *Know more*; *Invest wiser*; and *Build safer*. These principles are based on the five priorities of the HFA. The campaign has selected participating resilient pilot cities that are vulnerable to:

- (a) Floods; and
- (b) Drought events.

In sub-Saharan Africa, the resilient pilot cities selected are Narok and Kisumu in Kenya and Moshi in Tanzania. In these pilot cities, local authorities were found to be ill prepared to react to disasters. Additionally, limited financial and infrastructure capacity, and poor administrative linkages with regional and national authorities, affected these cities. When a disaster occurred, immediate disaster response depended greatly on international non-governmental organisations. It was also noted that (Disaster Risk Reduction) DRR was not incorporated into planning programmes for any of the three pilot cities, although its importance was recognised, especially its potential to guide and improve citywide activities.

Furthermore, pilot city local governments struggled to provide basic municipal infrastructure amenities, such as water supply and sanitation, waste disposal and storm-water drainage systems. As a result, DRR has not been regarded as a priority.¹⁰²

The lack of urban safety is another major urban hazard, especially in slum areas of Africa. Violence, crime and insecurity are some elements of urban safety. The poor layouts of these settlements, including the absence of street lighting, are some of the factors that contribute to the lack of safety. Urban safety is also related to the quality of housing stock. Poor materials, such as mud bricks, are often used in the construction of houses. These are prone to collapse during heavy rainstorms. It is also common to find business activities that use and store dangerous materials, such as flammable substances, in these settlements.

The upgrading of slums is among several types of urban renewal interventions that can provide urban safety for the poor. Safety in urban development can also be realised by reducing the urban divide exhibited in inequality in income, access to basic services and participation in political agreements between social groups. The social exclusion of some sections of the urban population is a source of frustration that influences the level of crime in urban areas.¹⁰³

Urban Risk Reduction: Lessons from Asia

Sub-Saharan Africa can draw lessons in urban risk reduction from experiences in Asia. The analysis of underlying factors of urban risk by Surjan and Shaw¹⁰⁴ provides insight into the phenomenon in Asia and its effects on the local environment. These causal factors are fundamental to our understanding of urban risk. They include the

urban population explosion, urban economic inequalities, inadequate urban administration in terms of regulating land use, an increase in unplanned settlements and the absence of basic services. These risk factors contribute to the vulnerability of urban populations.

The *Status Report and Inventory of Initiatives*,¹⁰⁵ which is based on mapping and analysis of urban risk issues in Asia, assesses the extent of urban risk and its causal factors and determinants. Some of these innovative measures have been community-led disaster risk-reduction initiatives. For instance, in a squatter settlement in the Yamuna River Bed in Delhi, risk assessment combined local insights and professional opinions.¹⁰⁶ This vulnerability and capacity assessment catalogued the capacity of the community and infrastructure, along with major hazards and risks and how these risks were perceived by all concerned. The end product was a community action plan that outlined risk-reduction measures. The risk-reduction actions identified were upgrading of physical surroundings, capacity building of community structures and community-driven environmental improvement activities. The use of action planning ensured the participation of all key stakeholders in decision making.

Community-led initiatives have been employed in reducing disaster risks in urban areas of sub-Saharan Africa. Experiences from Kanyama, a large sprawling peri-urban settlement of Lusaka, in Zambia, show that community initiatives that are put in place, such as health education supported by Oxfam (GB) and disaster risk reduction/Water, Sanitation and Hygiene (WASH) by CARE International and UNICEF, have contributed to a reduction in incidents of hazards such as cholera and diarrhoeal diseases.¹⁰⁷ Table 14.1 shows a marked reduction in the number of cholera cases reported to Kanyama Clinic, as a result of water and sanitation health hygiene campaigns in the community.

Table 14.1: Cholera cases reported at Kanyama Clinic, 2007-2011¹⁰⁸

Year (Rainy Season)	Number of Cholera Cases Reported
2007/2008	398
2008/2009	1 357
2009/2010	1 910
2010/2011	7

In order for community-led initiatives to be effective, local structures and actors need to be engaged by local authorities. Community-based organisations and actors are better placed to perform community disaster risk assessments and to identify appropriate strategies for building the resilience of their communities. The local authority should, therefore, play the key role of facilitating the various efforts within

the community and in integrating community-led activities in the overall urban development plans of their locale.

Conclusions

It is evident from this discussion that living in urban slums is characterised by conditions of squalor that can worsen vulnerability. The factors that affect the vulnerability of people living in urban areas of sub-Saharan Africa are wide ranging. They include underlying factors such as poverty and social exclusion of a large section of the urban population, demographic characteristics and location of settlements in poor and fragile environments. The housing stock and infrastructure in most urban areas of sub-Saharan Africa are often substandard or lacking. Many of these settlements are also situated in flood-prone or low-lying areas, where risks from the impacts of climate change, such as persistent flooding, are greatest.

Activities to reduce disaster risks, such as urban renewal programmes and new social housing aimed at the most vulnerable, need to be undertaken and escalated. In some cases, specific options for relocation of families living in risk areas are required. In this respect, the UN-HABITAT Safer Cities Programme is essential. Governments in sub-Saharan Africa should take full advantage of this initiative and also work towards empowering local governments to fulfil their mandate of providing safer environments for the urban population under their jurisdiction. This will require urban planning that will foster inclusiveness through the reduction of the 'urban divide' between rich and poor that currently characterises the urban areas in sub-Saharan Africa.

Reducing the urban divide calls for resource mobilisation and allocation that target the poorer sections of urban areas through urban renewal projects that promote inclusion of urban residents who are currently socially and economically excluded. Above all, concerted efforts are required that address poverty, which is the underlying factor for the vulnerability of the majority of the urban poor in sub-Saharan Africa.

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CHAPTER 15

Factors that Contribute to Vulnerability in Rural Sub-Saharan Africa

Kylah Forbes-Genade and Charity Chenga

Introduction

This chapter examines the increasing vulnerability faced by rural communities in the sub-Saharan African region and how the characteristics of life in these areas reinforce vulnerability. Drawing from qualitative research undertaken by the authors of this chapter and an academic desktop study of the topic, the chapter expounds on the characteristics that contribute to vulnerability in rural sub-Saharan Africa.

The growing frequency of disasters is not necessarily attributable exclusively to an increased number of physical hazards or the severity of hazards, but may have a stronger connection to the complexity of factors that contribute to vulnerability in the context of rural communities that are exposed to hazards.¹ The sub-Saharan region is home to some of the poorest people in the world, with over 400 million people living below the poverty line.^{2,3} The majority of the extreme poor in the region are based in rural areas. In sub-Saharan Africa, extreme forms of vulnerability have the potential to transform even minor hazard events into wide-scale disasters.

The chapter begins by defining the term ‘vulnerability’ in the context of disaster risk. ‘Vulnerability’ is one of the most widely debated concepts in disaster rhetoric. The concept of vulnerability is then examined within the framework of conditions present in rural sub-Saharan Africa that contribute to the vulnerability of individuals and households.

Understanding Vulnerability

The debate around the definition of the term ‘vulnerability’ in the context of disaster risk is ongoing.^{4,5,6,7,8} Multiple interpretations of the term reflect its perceived diversity of meaning and ultimately contribute to the challenges faced by disaster practitioners in applying it both in research and in reality. Numerous frameworks, approaches, paradigms, techniques and models have been used to explain the complexities of the concept.

The term ‘vulnerability’, within the context of disaster, is, for the most part, used to describe the conditions of a particular individual, group, population, community or household that undermine their ability to cope with adversity.^{9,10,11} In describing the vulnerability of a target group researchers seek to gauge the ability or inability of the target group to rebound. Wisner describes vulnerability as “the characteristics of a person or a group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural disaster”.¹² Ellis describes how prone individuals and households are to being unable to cope with uncertain adverse events that may happen to them.¹³

Adequate definitions must take into account both the relative and dynamic nature of the concept, despite its inherent association with conditions of poverty. According to the United Nations International Strategy for Disaster Reduction (UNISDR), the definition of vulnerability focuses less on the nature of the hazard and more on the components of vulnerability itself.¹⁴ Renaud and Perez suggest that ‘vulnerability is the condition determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards’.¹⁵ The perception of vulnerability as a component of a broader system allows for greater focus to be placed on social and demographic aspects of vulnerability. According to Brooks, Adger and Kelly, these include poverty, forms of marginalisation, access to quality housing and issues surrounding inequality.¹⁶

In this chapter, the definition of the term ‘vulnerable’ relies on Adger’s explanation of the term, with its reference to the ability or inability of the target population to rebound after stressors, shocks or hazards.¹⁷

Many practitioners use the term ‘vulnerability’ synonymously with ‘poverty’. Although vulnerability can be derived from a number of conditions associated with poverty – such as defencelessness, insecurity, lack of access to resources and isolation – the two terms are not interchangeable.^{18,19} Ultimately physical, economic, social and political factors are used to determine levels of vulnerability and the capacity to resist, cope with and recover from adversity.²⁰

Vulnerability is also a useful concept because, in combination with hazard exposure, it serves as a contributor to the determination of risk.^{21,22,23} Risk, by common definition, is the potential for damage that results from hazard occurrence on a vulnerable population.^{24,25} Vulnerability is an important concept within the framework of risk, as it helps with understanding the manner in which risk accumulates and what threats are faced by specific populations.

Factors that Contribute to Vulnerability

Aysan suggests a framework of factors that contribute to the vulnerability of individuals and households.²⁶ Specifically, he refers to the following elements:²⁷

- Lack of access to resources
- Weak individuals or buildings
- Degree of dependence on the environment and ability to access it
- Lack of access to information and knowledge
- Lack of public awareness
- Limited access to political power and representation
- Certain beliefs, customs and the disintegration of social patterns

Aysan's framework of factors that contribute to vulnerability serves as the basis for analysis of the rural sub-Saharan African context presented in this chapter. As a result of the similarities between some of the elements mentioned by Aysan, the chapter deals with the lack of access to resources, which is linked to "weak individuals or buildings" (based on their limited access to certain assets). Additionally, beliefs and customs are discussed alongside a discussion of the disintegration of social patterns.

Lack of access to resources

Resources are also referred to as 'assets' or 'capital', which are owned by or accessible to a community, household or individual.²⁸ They can include cash, credit, land, services or materials.²⁹ Access to resources, as a determinant of vulnerability, can be linked to the Sustainable Livelihoods Framework (SLF) approach, which suggests that the prevalence of assets or a lack of access to assets greatly affects the options available to households or individuals in times of adversity. The SLF approach is also linked to a preceding model, known as the 'Asset Vulnerability Framework', which further reiterated the inherent, yet inverted, relationship between decreased assets and increased vulnerability.³⁰

The SLF approach identifies five forms of capital: human, natural, social, financial and physical.³¹ Human capital reflects skills, education and human health status of members in a household. Poor rural communities tend to have poor health infrastructure, which often contributes to people only seeking clinic-based interventions as a last resort. As a result, simple illnesses and injuries develop into major crises that can threaten an individual's welfare.

The term 'natural capital' reflects access to or ownership of natural resources, such as: land for agricultural use, rental or development; water sources for irrigation or fishing; or, in many rural communities, reliance on forestry resources, such as trees, for lumber or charcoal production.³²

The participation in groups, associations and networks (whether formal or informal) creates opportunities and support systems that provide the foundation for what is referred to as 'social capital'. Aseka suggests that social capital is one of sub-Saharan Africa's greatest resources and is illustrated best in examples of village savings and loan (microfinance) endeavours in rural communities in the region.³³

Another resource that is lacking in many rural communities is home or property insurance.³⁴ In rural communities, the major causes of poverty are directly linked to a lack of access to financial capital.³⁵ Specifically, the factors that limit access to financial resources are linked to rural residents' traditional dependence on income from agriculture and agricultural production. The primary factors are linked to: landlessness, extreme land fragmentation, skewed tenure and exploitative share-cropping contracts, declining agricultural prices, rising cost of agricultural inputs, insecure income, debt bondage and weak market power.³⁶

Physical capital is a resource that can be found in the form of actual structures (e.g. sheds and traditional grain storage huts), equipment (e.g. bicycles, tractors and trailers), public infrastructure (e.g. bridges and paved roadways) and private infrastructure (e.g. drainage trenches).

In this context, access to any of the five forms of capital or resources enables the bearer to derive some form of benefit, which can provide alternative options in times of hardship associated with the impact of stresses, strains or hazards.

Originally, ex ante disaster risk management sought to establish assets in order to help households create a buffer against the threats posed by certain events.³⁷ Developed as a tool for analysing livelihoods and poverty,³⁸ the SLF has been applied to other circumstances, such as determining resilience of households to adversity. Limited access to resources can reflect the prevalence of poverty, as well as the increased vulnerability of a population. It limits the ability of a household, community or individual to rebound following negative circumstances. Again, this refers not just to financial resources, such as income, but also to access to public facilities, services or programmes, political representation and the economy.^{39,40} The poor are more likely to live and work in areas with high hazard exposure and they are less likely to be able to recover from devastation; this in comparison to people of affluence, who are characterised as those with adequate or advantageous access to resources. It is assumed that these people are much more likely to have the resources necessary to re-build should their properties experience damage from hazard impact.⁴¹

Other circumstances undermine the access of certain groups to resources in sub-Saharan Africa; for example, disempowering indigenous customary and statutory laws that forbid women to own land or access credit. These laws reinforce the vulnerability of women.^{42,43} According to the Al-Zubaidi and Assubuji:⁴⁴

Access, control and ownership of land largely remain the domain of male privilege, entrenching patriarchal structures of power and control over community resources, history, culture and tradition. There are many women in Africa who are financially unable to purchase land and who are often denied access to credit or loans.

In some African countries, such as Nigeria,⁴⁵ married women still need consent from their husbands before seeking a loan or credit; and in Swaziland this is needed even to open a bank account. (This requirement is considered to be in violation of international human rights law.)⁴⁶ in many countries in Sub-Saharan Africa, women can only access land or proper housing through male relatives, which creates a scenario of dependency on family relations and marital status.^{47,48}

According to customary law in Somaliland, women are seen as 'only temporary members of a family' – as they are bound to join another tribe upon marriage – and therefore cannot inherit any immovable assets, such as land.⁴⁹ Similarly, Marjolein Benschop of UN-HABITAT reported to the Commission on Sustainable Development in 2004 that with regards to co-ownership of land between a husband and his wife, a Ugandan farmer compared his wife to a tractor.⁵⁰ He explained that he had purchased his tractor and, similarly, he had also paid the traditional dowry to buy his wife. He argued that his tractor was his property because of the money exchanged and that the same principles of ownership existed in relation to his wife, for whom he had paid a dowry. He could not appreciate an argument that suggested that his wife, although his property, could be allowed to own property herself. In this context, women are regarded not as a temporary member of a family, but rather as property.

Weak buildings or weak individuals

In general, the term 'weakness' has connotations of limitation; it is in this regard that Aysan suggests that 'weak' buildings or 'weak' individuals are factors that contribute to increased vulnerability. For one reason or another, the perception exists that individuals and buildings in sub-Saharan Africa lack the full capacity to withstand hazard-related adversity.

Whether as a result of inherent defects or from disabilities developed over time, people or structures that exhibit characteristics of weakness may be less able to withstand the effects of hazards, stressors or strains than those that do not. Examples of weak people could be malnourished children or children born with the Human Immunodeficiency Virus (HIV) as a result of mother-to-child transfer, which is prevalent in sub-Saharan Africa, particularly among women of child-bearing age.⁵¹ Further examples for this region include the influx of HIV and Acquired Immune Deficiency Syndrome (AIDS) affected adults, who, because of the effects of the syndrome, are not physically able to make a full contribution to society. In this way, communities are robbed of young adults with valuable skills.

The impact of the HIV epidemic has also contributed to the growth of child-headed families, which are a result of the death of either one or both parents from AIDS-related diseases.⁵² These households could be considered weak on the basis of their limited ability to earn a sustainable livelihood, as many household members are of school age and they drop out of school (often times ostracised by stigma and

discrimination).⁵³ In terms of age, the elderly are also considered weak and potentially vulnerable.

Within the context of structures, weaknesses can be used to describe faulty designs or ineffective materials. Traditional structures in the region range from mud structures to combinations of homemade brick-and-mud or small concrete buildings.

Weakness can also be considered in terms of assets and resources, which are discussed above. Ultimately, weaknesses are reflective of a lack of a particular characteristic, which we discuss in the context of having 'limited resources'. Physical weakness of individuals may be seen in relation to a lack of human capital in terms of physical health. Weaknesses in structures can be linked to unsafe, unstable and unprotected buildings or homes. Weak physical structures can be related to diminished physical assets or may be the result of limited financial resources, which can undermine people's ability to construct sturdier, safer structures or to relocate to less hazard-prone areas. Many rural dwellers continue to reside in isolated homesteads or villages in highly hazardous and marginalised areas often characterised by desert terrain, flood plains and steep unstable hillsides. Poor families depend on limited physical resources to construct traditional rudimentary housing structures for shelter. Physical stability is also questionable, and heavy rain and wind often erode the structures, resulting in their collapse. Poor families often have limited funds to carry out repairs. The combination of poor shelter structures and weak individuals reinforces the vulnerability faced by certain individuals that reside in rural communities.

Degree of dependence on environment and inability to access it

In rural areas, people depend significantly on the environment, particularly for their livelihoods. Rural communities tend to be agrarian in nature, with 60 per cent of the population dependent on agriculture for a living.⁵⁴ This creates challenges because of the finite nature of land and natural resources and, consequently, adds to the vulnerability of these people. In light of the forecasted implications of global phenomena such as climate change, particularly in relation to increased frequency of floods and droughts, and changes in weather patterns and precipitation, the quality of the environment and the abundance of natural resources available are threatened. The dependency of a large portion of the population on limited natural resources, such as minerals, only serves to reaffirm and reinforce their vulnerability. This is also linked to dependence on a single source of income, which once again creates a scenario in which any form of flux or failure in this area undermines what little security farming communities have.

Countries such as Sierra Leone, Niger and Angola lead the pack in terms of GDP growth.⁵⁵ What these three countries have in common is 'new money' from mineral exports. They join a long line of other countries in the region that enjoy enormous mineral wealth, but that have seen increased poverty levels and rising inequality accompany their fortune. This is often referred to as the 'resource curse'.⁵⁶

Where policy, legal frameworks and regulatory regimes are weak, they have contributed to the resource curse. They have done this by allowing multi-national and transnational corporations to extract enormous profits and engage in corrupt practices, in collusion with some national elites. This has all been at the expense of local populations and national development agendas.⁵⁷ For rural communities, this is compounded by: loss of livelihoods through having to make way for large mining corporations; large inflows of mainly unaccompanied male internal and external migrants; and the degradation of rural environments because of high levels of pollution.

The implication for the well-being of such communities is the emasculation of the cultural structures that have to compete with a high-profit industry that enjoys government support in the name of national interest. These large corporations gain the trust of communities by creating unrealistic expectations through promises of increased employment and improved infrastructure. Such undertakings encourage communities to want to benefit from the livelihood activities. However, in many instances, the mining companies hire migrant workers instead of employing local community members. This has serious effects on the level of criminal activity as a way of dealing with loss of livelihood within communities. Inability to compete economically with unaccompanied migrant employees results in high rates of prostitution, which have implications for the culture, health and well-being of community members.⁵⁸ Mining communities in the sub-Saharan region are synonymous with high rates of infectious diseases, such as tuberculosis, and HIV/AIDS and other sexually transmitted diseases.⁵⁹ In addition, while illnesses such as mine operation-related cancers have largely been played down or hidden from community members, and from the public, rural community members carry the burden of dealing with the outcome of these illnesses.⁶⁰

In addition to degrading the rural landscape, mining operations have a heavy impact on water, which is an important scarce resource. Many rural areas that are synonymous with mining report an increasing drop in the water table, making access to clean water difficult.⁶¹ Not only do mines cause the level of the water table to drop in the rural areas in which they operate, but mining activity also pollutes the remaining water. Studies have indicated that acid rain and chemicals discharged from mining activities have been found in local water supplies. This contamination has negative implications for human, animal and plant life.⁶²

As a way of compensating for livelihoods lost due to mining, most rural community members now engage in artisanal mining. Between 100 and 200 million people globally depend on individuals that are directly employed in artisanal mining. The number of people that work as artisanal miners is between 20 and 30 million, most of whom are located in rural areas. These figures highlight the significance of this activity to rural economies. 'Artisanal mining' refers to extractive activities that are informal and often 'illegal' and that are usually carried out by the rural poor to

supplement subsistence farming activity. Artisanal mining activities are typically performed using fairly rudimentary methods and tools.⁶⁵

Artisanal mining plays a significant role in Tanzanian mining, in terms of both contribution to economic development (through mineral exports) and level of employment of the population. In recognition of these benefits, the Tanzanian government encourages artisanal mining by local community members, by allocating land on which they can undertake such mining. While this may appear to be a policy that empowers rural community members, issues pertaining to poor governance, health and safety paradoxically heighten the vulnerability of community members. While the allocation of mining land is intended for rural community members, most allocations are in fact made to elite citizens who live in towns. Research conducted by Dr. Chenga in Tanzania in 2008 into the social and economic impacts of artisanal mining on communities, served to provide a unique perspective wherein a community member explained:

The agreement is that we give a percentage of our mine proceeds to the mine owners. It is like we are renting. But the rent is based on how much we mine. So if we want to make a good living from mining we need to work very hard and take chances that risk our lives.

Overall, artisanal mining has had a profound effect on the rural environment, in terms of both the landscape and cultural and traditional livelihoods.



Figure 15.1: Example of mine entrance in artisanal mining

(© Dr Charity Chenga)

Figure 15.1 presents photographs of a mine entrance in the Tanzanian artisanal mining sector, which show how miners descend underground. The second photograph illustrates how miners send equipment underground and bring soil and minerals to the surface. The hole is just wide enough for a man carrying a few items to manoeuvre

down. The hole can go as deep as 70 feet. There appear to be no health and safety laws that specify the size of the hole or any other protective requirements. Although women participate in artisanal mining, men mainly work underground. Women often participate indirectly (mainly on the surface), doing work such as breaking stones to extract minerals; selling food, alcohol and consumables; and dealing in drugs to derive a menial income.



Figure 15.2: Example of mine entrance in artisanal mining

(© Dr Charity Chenga)

Other more dangerous methods of descending underground are adopted, as children are employed in this work. Artisanal mining is perceived as a money-making venture and a way out of rural poverty.⁶⁴ Subsequent interviews by Dr. Chenga on the social and economic impacts of artisanal mining purports that a community member from Tanzania expressed:

Yet very few people make the money or ever get out of the poverty spiral. This dream of the big money has entrenched the young to the extent that most young people and children are opting to leave school to work as artisanal miners. Numerous deaths and injuries take place, but are not always reported. Sometimes bodies are not brought up to the surface.



Figure 15.3: Unprotected artisan miner handling raw mercury – used in processing gold

(© Dr Charity Chenga)

Health problems are related not only to the excavating process but also to processing the gold. Unfortunately, direct contact with chemicals such as mercury and cyanide has long-term health repercussions, such as toxic effects on the nervous, digestive and immune systems, and on the lungs, kidneys, the skin and the eyes.⁶⁵ This has consequences for the already poor health infrastructure. In the same way that HIV/AIDS has devastated disadvantaged communities in sub-Saharan Africa, cancer is gaining momentum.⁶⁶



Figure 15.4: Land degradation derived from artisanal mining activities
(© Dr Charity Chenga)

Figure 15.4 shows the effects of artisanal mining on the landscape of rural communities. The extent of land degradation is a problem not only from an aesthetic perspective but also from a use perspective. Underlying factors affect the future use of soil in the area. This type of mining generally poisons the water and surrounding soil, which has implications for agricultural activities and the environmental health of the area for future generations.

Lack of access to information and knowledge

Another factor linked to conditions that contribute to vulnerability is the lack of access to information and knowledge. Instances arise where information or knowledge is not transmitted by those that are informed to those that lack awareness.⁶⁷ In some instances, governments or scientific authorities fail to communicate information to the public in a manner that is comprehensive, appropriate and relevant. In parts of sub-Saharan Africa, access to information and knowledge is limited by such common factors as language. In Chad, government broadcasts have now commenced in Arabic, which has left many non-Arabic speakers unable to understand

what important government broadcasts convey regarding policies, recent news and warnings.⁶⁸

Lack of public awareness

Owen and Kemp⁶⁹ suggest that little research has been conducted on the overall diversity of rural communities. Lockie et al.⁷⁰ suggest that communities are generally heterogeneous in their values, interests and perceptions and in the ways that they respond to hazards. Lack of public awareness is a contributory factor to the vulnerability of rural communities in sub-Saharan Africa.⁷¹ Creating public awareness can be part of the overall approach to reducing community vulnerability. It is a valuable strategy for providing useful information, educating the public, making an economic case for prevention and creating community support and partnerships in making the necessary changes to reduce vulnerability.⁷² Despite the key role of public awareness in reducing vulnerability within communities, poor communication infrastructure within rural communities can impede effective public awareness campaigns. Furthermore, public awareness campaigners can exacerbate the vulnerability of rural communities by disregarding rural communication structures.⁷³

Rural communities in sub-Saharan Africa experience unique social constructs surrounding political affiliation, gender, culture and ethnicity discrimination, which can have an impact on their ability to benefit from public awareness programmes and invariably play a significant role in rural community vulnerability. Some of these constructs include:

- Availability of public awareness programmes
- Adequacy of public awareness programmes
- Appropriateness of public awareness programmes
- Power relations
- Informed consent

Availability of public awareness programmes, in any context, is generally determined by expert knowledge about issues that require public awareness, resources and political will. Consequently, most programmes are usually responsive to and originate from external sources, as opposed to being proactive and originating in rural communities.⁷⁴

This top-down approach can result in what Freire⁷⁵ refers to as a form of learning characterised by ‘banking’, where the facilitator ‘deposits’ information in the community members and it is not ‘empowering’ Freire suggests that empowerment can be achieved through dialogue, so that public awareness campaign facilitators are able to learn how rural community members understand the world. In this way, the facilitators understand how community members can learn. To a large extent, this approach empowers rural community members to take ownership of issues in their communities.

Effective public awareness has been limited by political turbulence in the sub-Saharan region, including colonialism, liberation struggles and the subsequent transformation processes that have been dogged by violent elections, HIV/AIDS pandemics and economic strife. These problems have contributed to distorting the documented history of most rural communities. Documentation of rural history by rural community members has been limited. In most cases, the history that has been documented has been written by representatives of oppressive regimes that have either colonised the countries or ruled these areas. Consequently, these writers have ensured that the history documented favours their interests.^{76,77,78} Public awareness campaigns have failed to understand and interpret cultural practices across rural communities in sub-Saharan Africa. This failure has had implications for rural community resilience by undermining or understating the positive contributions of rural communities. Most high profile research conducted in sub-Saharan Africa relates to specific problems in given areas, such as the effects of climate change, deforestation, food security, poverty and HIV.^{79,80} It overlooks the real problems that plague communities and avoids the issues that erode the ability of these communities to build resilience.

A discussion of how resources are allocated to public awareness programmes can shed some light on why public awareness campaigns can further reinforce the vulnerability of sub-Saharan rural communities. Service providers such as public health professionals, environmentalists, government officials, universities and non-governmental organisations (NGOs) undertake public awareness campaigns. All these organisations have to work within a budget and specific guidelines with regard to what type of programme to undertake, how to undertake the programme, where to locate the programme, and for which community to undertake the programme.⁸¹ These decisions are made away from the settings where the campaigns run and without the input of the relevant community members. Furthermore, most universities and NGOs work within a specific framework, which may not be aligned to the needs of rural communities but rather have external agendas. This can inadvertently result in escalating community vulnerability by overlooking critical considerations, adding to vulnerability or creating a false sense of security.

Some NGO public awareness campaigns could be construed as insensitive and oppressive. An HIV/AIDS public awareness campaign undertaken in a South African mining community provides an example of how insensitive practices by NGOs can result in disempowering experiences for community members. The focus of this particular campaign was voluntary HIV/AIDS testing and the campaign was called *Get Tested*. To get the ball rolling, the NGO set up a temporary HIV/AIDS centre during its five-day publicity campaign in the mining community. The testing centre consisted of four tents, which functioned as follows:

- The first tent played the dual role of welcoming community members and acting as a venue for pre-test counselling.
- In the second tent, the blood tests were carried out.

- The test results were given in the third tent.
- Those with HIV/AIDS positive results were directed to the fourth tent to get information about what social benefits they could receive from the state.

Several issues were raised by community members, who were unhappy about the approach of the NGO, as follows:

- The pre-test counselling was not private because the counselling session was conducted with a group of up to 20 people at a time. Consequently, there was no opportunity to clarify personal issues or anxieties.
- There was no post-test counselling.
- Combining the use of one tent to welcome community members and undertake group counselling put pressure on people to participate in the HIV/AIDS testing.
- It was difficult to keep a positive HIV/AIDS result confidential from other community members because people knew that if a person was directed to the fourth tent, they were HIV positive.

A community member reported that a married woman from the community who was found to be HIV positive committed suicide on her way home. The married woman had not informed her husband that she was going for HIV/AIDS testing and was too scared to tell him about the test results. This example highlights issues pertaining to informed consent and power relationships in terms of public awareness campaigns in rural communities.⁸²

Limited resources have an impact on public awareness campaign follow-ups. Follow-ups on awareness campaigns are important because they provide a way of evaluating the outcomes of the campaigns. Political will has a lot of bearing on resource allocation to rural areas. It can be argued that lack of political will constitutes a limiting factor to public awareness within these environments.⁸³ Avila and Gasperini⁸⁴ suggest that generally rural areas are given low priority in resource allocation in most sub-Saharan countries. Consequently, inadequate and at times inappropriate resources are largely allocated to public awareness campaigns to rural areas.

This is despite observations by Bratton et al.⁸⁵ that rural voter turnout in sub-Saharan African countries was higher than urban voter turnout in 10 out of 12 countries surveyed. The exceptions were Tanzania and South Africa, where urban voters were slightly more active. Since rural communities provide the higher voter turnout, it would be expected that their needs would be prioritised to reflect their vote. The low priority given to rural communities could therefore be perceived as being due to a lack of political will.

Politically and socially, it is predicted that the merger between communication and computing technologies will increase cooperation among various groups across national borders, leading to the emergence of technologically savvy groups

of people working together.⁸⁶ Utilising such media can provide an effective tool for public awareness campaigns. The effective use of social media, such as Facebook, to achieve political change was demonstrated by the Egyptian revolution that ousted President Mubarak.⁸⁷ In sub-Saharan African rural communities, it is difficult to use social media to similar effect because of the poor distribution of both electrical power grids and landline telecommunications networks, coupled with the high costs of computing devices and low rates of computer literacy. The internet remains a luxury good that benefits only a small political and commercial elite.⁸⁸ On the other hand, cell phones and internet-enabled mobile phone devices are becoming more available across the continent. Aker and Mbiti⁸⁹ found that while only 10 per cent of Africans had mobile phone coverage in 1999, primarily in North Africa and South Africa, by 2008, 60 per cent of the population in Africa could get a signal. Technological development of mobile phone handsets has increased access to cheap mobile phones that have internet applications. This has resulted in increased opportunities for rural community members to participate on social media platforms such as Twitter.⁹⁰

While increased access to communication technology facilitates a mode of communication, issues related to the language used by and the ethnicity of the public awareness campaign personnel can affect the vulnerability of rural community members. The language used during public awareness campaigns can have an impact on access to information because the community members may not speak or understand the language used for the public awareness campaign or the technical terms used to explain the issues.⁹¹ The local language may not have terms for concepts such as 'climate change', 'HIV/AIDS' and risk.

As indicated above, most public awareness campaigns are funded by international NGOs, which may or may not be of the same ethnic origin or race as the rural community members. Todd⁹² alludes to the potential power relationships that can develop in community development and public awareness campaigns where racial differences exist between community development practitioners and community members. He suggests that community development creates the discursive and performative space for white bodies to know, evaluate and intervene in the collective lives of racialised bodies. The racial differences also create the possibility for white subjects to imagine themselves as being heroic in the struggle against racism. The problem with such a hopeful heroic stance is that it tends to obscure the multiple effects of community work. Some of these effects facilitate progressive change and others re-inscribe oppressive relations (or draw on practices or perspectives that rely on, and thus sustain, existing practices of inequality).

Community resettlement is a key component of the colonial project and is influenced by the ideology of colonialism.⁹³ The paternalistic relationship that is maintained between the former colonists and the colonised, in terms of the majority of the public awareness projects in rural areas, continues to be an oppressive relationship.⁹⁴ Freire suggests that, in some cases, the former oppressors unwittingly continue to

oppress the oppressed, even when they have joined the oppressed in the struggle for liberation. Freire suggests that it is not difficult for the former oppressors to find themselves in this position because the oppressed tend to open the way for them to do so, since: 'They call themselves ignorant and say the 'professor' is the one who has the knowledge and to whom they should listen'.⁹⁵ Consequently, lack of trust in their ability to free themselves becomes a factor in rural community vulnerability.

The effects on the outcomes of a public awareness campaign of having a public awareness campaigner coming from a different racial or ethnic background to the rural communities they serve may not be straightforward. The difference in ethnic or racial background may have a positive or negative impact. For example, a public awareness campaigner from a different ethnic group and race to that of the community members may result in community members paying more attention to the personal attributes of the campaigner than to the topic of the campaign.⁹⁶ Ethnic and racial differences can detract focus from the campaign and negate the outcomes of the campaign.

Traditional structures in most rural communities in sub-Saharan Africa include effective communication methods, with regular (monthly) community meetings with the chief, which are attended by at least one member of each household. These forums can provide an effective platform for building public awareness regarding issues that relate to community vulnerability matters.

As mentioned in section 15.3.1, the lack of social capital is connected to community vulnerability. This factor leads to another characteristic of most rural communities in sub-Saharan Africa that has an impact on vulnerability through lack of public awareness. This is the type of social capital that exists within these communities. The type of social capital within these communities can constitute positive or negative resources, which may, in turn, have an effect on vulnerability.

Most rural communities are characterised by bonding social capital. Bonding social capital is strongly characterised by strong bonds (or 'social glue'); for example, among family members or among members of an ethnic, cultural or economic group. This represents the construction of social networks with those of like mind.⁹⁷ Bonding capital can be useful in public awareness campaigns, as this creates a tendency to share information. However, account needs to be taken of the context and nature of the campaigns being undertaken because, while bonding capital can be useful for public awareness campaigns, Ramirez-Sanchez and Pinkerton⁹⁸ suggest that resource scarcity decreases the tendency to share information.

To a large extent, resource scarcity could be interpreted as a prelude to social power relationships developing in rural communities. Rural communities are not homogeneous and public awareness campaigns must take this into account if they are going to be effective in reducing vulnerability. Gender, age, citizenship, language, ethnicity and employment status are social constructions that have an impact on inequality in accessing public awareness campaigns.⁹⁹

Limited access to political power and representation

The sub-Saharan political arena is plagued with persistent political instability from civil wars, weak democratic systems, a propensity for violence, and massacres in the name of ethnic and religious beliefs. Other challenges that face rural communities in sub-Saharan countries include: high profile poor governance practices, international economic sanctions, pandemics such as HIV and natural disasters.^{100,101} Conflict has destroyed many civil institutions in sub-Saharan Africa. The lack of security, fear of violence and the absence of democratic institutions can be seen as the other main issues that affect human vulnerability and preparedness in sub-Saharan Africa.^{102,103}

The focus of most politicians is to retain and maintain political power.^{104,105} However, political ambitions can leave marginalised and disadvantaged communities (such as those in rural areas) as key targets for supporting their political success. As indicated, despite being over-looked and disregarded (through lack of representation, as illustrated by the poor service provision in rural areas), rural communities still record the highest number of votes in most sub-Saharan countries. The high election turnout and poor political representation may help to confirm reports of intimidation and the threats of death associated with political elections in rural communities. Where the political process spirals into civil war, women and children become the most vulnerable, with children enrolled as child soldiers and women being raped or forced to offer sex in exchange for life.¹⁰⁶ All of these aspects of vulnerability have the potential to contribute to long-term health implications, including mental health problems and HIV/AIDS.¹⁰⁷

Even where countries do not degenerate into civil war, the geographical location of political structures (such as Parliament) can contribute to a lack of representation for some rural populations in sub-Saharan countries. For example, the governing structures in sub-Saharan countries are based in capital cities, which are far from rural areas. Despite being voted in as political representatives of constituencies that include rural areas, most politicians and political leaders do not live in the rural areas. They are only visible in the rural areas during elections; thereafter, they are not seen. Consequently, most rural community members are disenfranchised in terms of representation, despite having actively participated in elections.¹⁰⁸ As expressed by a community member in rural South Africa: ‘... the politicians spend all their time here when campaigning for positions and promise all sorts of things, but once they win the election, they are not seen again’.¹⁰⁹

Rural communities are vulnerable not only in terms of the negative effects of conflict and electoral intimidation but also as a result of the misrepresentation that stems from manipulation by political regimes or international political groups.^{110,111} In South Africa during the apartheid regime, rural community members (especially those given chieftainships in the homelands) were manipulated into maintaining and facilitating separate development.¹¹² This has had implications for the relationship between chiefs in South Africa and the ruling party – the African National Congress

(ANC).¹¹³ Ousman argues that radical Islamists are targeting fragile and conflict-affected states in parts of sub-Saharan Africa, where they motivate 'exit movements' from state control among African Muslim communities. These exit movements are 'mostly anti-system, mostly grassroots ... with a variety of political, social and economic goals ... which are often beyond the control of the state'.¹¹⁴

Political vulnerability does not affect all rural community members equally. Al-Zubadi and Assubuji¹¹⁵ see land as being not only a source of food, employment and income: it also provides social prestige and access to political power. Three main issues that pertain to land inequality in rural areas have a profound influence on political vulnerability and representation for community members. These are:

- Gendered access to land (as indicated above)(Section 15.3.1)
- Mineral-rich land (as indicated above)(15.3.3)
- Land grabs

Over 50 years ago, the decolonisation of African territories began. The next half-century may see the continent re-colonised. Parris suggests that the new imperialisation will be less benign. He explains that great powers are not interested in administering wild places anymore, still less in settling them: just raping them.¹¹⁶ Before 2008, the global demand for arable land was less than 4 million hectares a year. By the end of 2009, global demand for land had increased significantly and 56 million hectares had been bought and brought into cultivation, approximately 70 per cent in Africa.¹¹⁷ Approximately 80 per cent of the continent's poor live in rural areas and depend mainly on agriculture for their livelihood.¹¹⁸ The sector accounts for about 20 per cent of Africa's GDP, 60 per cent of its labour force and 20 per cent of total merchandise exports. Agriculture is the main source of income for 90 per cent of the rural population in Africa.¹¹⁹

Land grabbing by local elites and global investors is another factor that contributes to vulnerability of rural communities in sub-Saharan Africa. The traditional land ownership practices in the region make these community members vulnerable to exploitation by external investors. Under communal tenure systems: portions of land are held by individual families; other portions are held and managed in common by the community, tribe or group. These 'common resources' include grazing land, forests or woodlots, communal food gardens and shared water resources. Under communal land systems, people do not hold a title deed and rarely have other evidence of their land rights, such as permits or certificates of occupation.¹²⁰

The Oakland Institute¹²¹ suggests that while news coverage to date has emphasised the role that countries (including China and India) have played in the acceleration of land acquisition in Africa, investigation shows a major role being played by Western firms, wealthy US and European individuals, and investment funds with ties to major banks (such as Goldman Sachs and JP Morgan). Vidal and Provost¹²² reported that institutions and organisations that make large deals, which they refer

to as 'land grabs', include Harvard and Vanderbilt Universities. Other key investors include several Texas-based interests associated with a major 600 000 ha South Sudan deal, which involves Kinyeti Development LLC (an Austin, Texas-based 'global business development partnership and holding company' that is managed by Howard Eugene Douglas, a former United States Ambassador at Large and Coordinator for Refugee Affairs).¹²³ Institutions, including Harvard and Vanderbilt, reportedly use hedge funds to buy land in deals that may force farmers out.¹²⁴

It could be argued, from some of the evidence, that under the auspices of aid, health and education, and the imposition of democratic requirements, human rights and the free market, some countries that do not 'toe the line' may be faced with crippling sanctions, because of abuse of political power, in order to facilitate land grabs by Western countries. The Oakland Institute¹²⁵ and Vidal and Provost¹²⁶ found that many European companies are also involved, often with support provided by their governments and embassies in African countries. For instance, Swedish and German firms have strong interests in the production of biofuels in Tanzania. Major investors in Sierra Leone include Addax Bioenergy from Switzerland and Quifel International Holdings (QIH) from Portugal. Sierra Leone Agriculture (SLA) is actually a subsidiary of the UK-based Crad-I (CAPARO Renewable Agriculture Developments Ltd.), which is associated with the Tony Blair African Governance Initiative. Most of these investors claim that the land deals were conducted in a responsible way, by investing in African agriculture, setting up businesses and employing people. Karlsson¹²⁷ suggests that they also claim that they are making the land more valuable and productive. The justification for land grabbing has been that they are going to undertake more efficient agricultural production and increase production, on the assumption that African farmers lack the skills for modern farming.

This analysis fails to take into account the heavily subsidised products in developed countries, which contribute to unfair competition for African agricultural products.¹²⁸ As an example, 40 per cent of the European Union's budget goes to agricultural subsidies: thus out-competing the production of poorer countries.¹²⁹

The lack of transparency regarding land deals in Africa makes it difficult to ascertain the extent of land transactions or the amount involved in the unscrupulous deals. Land-related corruption weakens the local farmer's situation and could prevent any positive effect of land transactions on Africa's economy. African governments are often tempted by promises of economic growth and innovation in agriculture by external investors. Consequently, land is being diverted to commercial interests, rather than to smallholder farmers.¹³⁰ It could be argued that while issues of corruption are focused on African government officials, Western and other land-grabbing countries and institutions also play a significant role in swaying the balance of land ownership in unfair ways – away from local ownership toward foreign interest with the ability to pay top dollar. Unregulated land purchases made by foreign investors are

forcing millions of African smallholder farmers off their land, to make room for export commodities such as cut flowers and bio fuels.¹³¹

Karlsson¹³² identifies three aspects of conflict related to land grabs: the foreign investor, the African government and the rural African farmers; this is usually referred to as the 'triangle of interest'. However, the negotiation field is uneven, as foreign investors tend to benefit the most, partly due to widespread corruption amongst African governments. The African farmer is the most vulnerable in this triangle, in terms of both negotiation and the outcome of a deal. Dowden¹³³ argues that institutional gaps at country level, lack of documented rights claimed by local people and weak consultation processes have resulted in farmers being displaced in favour of external investors' interests. On an uneven negotiation field, investors tend to gain much from the investment, while the locals barely benefit from it at all.

The investigation by the Oakland Institute revealed several unscrupulous transactions and abuse of rural community members. The Oakland Institute reports that land purchases are resulting in the displacement of small farmers, environmental devastation, water loss and further political instability (such as the food riots that preceded the Tunisian and Egyptian revolutions). Anuradha Mittal, Executive Director of the Oakland Institute, noted that some investors admitted finding it easy to 'seal a deal in Africa'. Mittal cited an example where one investor explained that they could usually 'get what they wanted' in exchange for giving a poor, tribal chief a bottle of Johnnie Walker whisky.^{134,135} At the same time, they find that, as with most mining deals in the region, investors promise progress and jobs to local chiefs, but they do not deliver on their promises. Frederic Mousseau (a policy director at the Oakland Institute) noted that: 'We have seen cases of speculators taking over agricultural land, while small farmers, viewed as squatters, are forcibly removed with no compensation.'¹³⁶ A former Ethiopian communal farmer, who had been forced to lease land, explained, 'When they first came, they told us an investor was coming and we would develop the land alongside one another. They didn't say the land would be taken away from us entirely'.¹³⁷ Matondi et al.¹³⁸ note that there is a fear that the majority of Africa's poor may end up as spectators, with consequences in terms of cultural and social disintegration.

According to the World Bank, 'one billion people go to bed hungry every night'.¹³⁹ At the same time, millions of acres of land available for agriculture in Africa are said to be poorly used, if used at all. This could be the justification for increased land purchases by those who perceive themselves to be more efficient users of land.¹⁴⁰ However, it could also be argued that the reason why there is limited land elsewhere for agricultural use is because the same people who are land grabbing have opted for livelihoods that degrade their own land. Now the land grabbers displace rural community members and bulldoze their way onto the land of those who have maintained and sustained their land. It could further be argued that, to a large extent, developed countries are dealing with their problems of poor access to land by taking

from developing countries, while appearing as if they are doing some good to the developing world.^{141,142} It could be construed that a relationship exists between the financial crisis that hit the world in 2008-2009 and the jump in land purchases in Africa from 4 million hectares to 56 million hectares in the same year. Furthermore, the unprecedented rise in food prices in developed countries in the same period can be perceived as contributing to the excessive drive to purchase land in sub-Saharan Africa.¹⁴³

Certain beliefs and customs

Sub-Saharan Africa is home to 62 per cent of the world's HIV cases; more than 14 000 people are infected daily with HIV and 11 000 people die daily from HIV/AIDS-related illnesses. At the same time, sub-Saharan Africa is home to 70 per cent of the poorest people in the world.¹⁴⁴ HIV infection is mostly confined to the poorest, who constitute the most infected in Africa. It is not simply that information, education and counselling activities are unlikely to reach the poor, but that such messages are often irrelevant and ineffective.¹⁴⁵ The burden of HIV/AIDS does not fall evenly or equally. WHO and UNAIDS global estimates suggest that women comprise 50 per cent of people living with HIV. However, in sub-Saharan Africa, women constitute 60 per cent of people living with HIV. In other regions, men having sex with men (MSM), injecting drug users (IDU), sex workers and their clients are among those most-at-risk for HIV, but the proportion of women living with HIV has been increasing in the last 10 years.¹⁴⁶

Mswela¹⁴⁷ found that the implications of HIV/AIDS, gender inequality and gender violence, and more specifically certain cultural practices and customs, contribute to women's subordination and inequality. This, in turn, increases women's vulnerability to exposure to HIV infection. Specific customary practices and habits facilitate the spread of the virus in South Africa. These are, for example, resistance to the use of condoms, as a result of specific sexual and cultural norms and values; social norms that allow or promote high numbers of sexual partners, especially among men; the phenomenon of an extended family household structure; preference for a male child; the practice of polygamy; the bride price practice; wife inheritance (levirate); the prevalence of superstitions; and adherence to the culture of silence.¹⁴⁸

It is ironic that the purpose of a specific custom may initially have been to provide financial security or stability for women and children but that the effect may have changed over time. Instead, customs now add to the increased vulnerability and marginalisation of certain groups. Therefore, it can be argued that, in most cases, it is not the customary law per se that leads to HIV/AIDS, but the interpretation over time and the adaptation to changes that lead to vulnerability of people in rural communities. It could be argued that the combination of the time lag between public awareness campaigns on HIV/AIDS and poor and inadequate awareness campaigns that point a finger at the customary practices of the majority of people in rural communities

in sub-Saharan Africa contributes to the vulnerability of rural communities to HIV/AIDS.

Ocholla-Ayayo¹⁴⁹ suggests that negative attitudes towards certain cultural practices, such as polygamy and wife inheritance, have consistently received negative publicity by authors and researchers from the developed world, to the extent that the elites in developing countries perceive traditional cultures as being backward. Therefore, traditional practices are not incorporated into legislation to the extent that they should be. Ocholla-Ayayo¹⁵⁰ argues that in urban affluent environs the perception is that any cultural practices, values and beliefs are rural based, backward and “primitive” and that they have outlived their intended purpose. Traditional herbal medicines, for instance, are considered dirty and unhygienic. Meyer-Rochow and Chakravorty¹⁵¹ concur with this observation, suggesting that traditional knowledge is being lost because people are ashamed to admit to undertaking traditional practices such as eating insects or using traditional medicines. They explain that people feel that they will be perceived as uncivilised and not be accepted by civilised people from Western and industrial societies.

Meyer-Rochow and Chakravorty¹⁵² argue that traditional ethno-biological knowledge and the habit of eating foods such as insects and using herbs and insects as an integral part of local therapies are nowadays confined to traditional living. This traditional way of living is largely found in indigenous societies of regions. These therapeutic uses are often a closely guarded secret and only passed on to certain individuals from one generation to another by word of mouth. Transfer of knowledge in this way is an age-old practice and an accepted socio-cultural attribute among ethnic societies. However, many of these indigenous societies have apparently lost confidence in their own culture and traditions and are far too readily abandoning local practices and replacing them instead with unsuitable Western ways.

The sub-Saharan rural context has been characterised by conditions that contribute to vulnerability, such as the HIV/AIDS pandemic, economic upheaval (such as mining development), economic downturn and revolution, which has required rapid cultural behavioural changes.¹⁵³ These hazards have left sub-Saharan cultures unable to respond effectively.¹⁵⁴

Conclusion

This chapter not only highlights the factors implicated in contributing to the vulnerability of sub-Saharan rural communities but also considers their complexity. The overall conclusion is that some of the major issues that relate to vulnerability in these communities actually emanate from the consequences of activities undertaken in urban and industrialised areas in the name of development.

The chapter illustrates how the social constructs embroiled in the ideological standpoint of the dominant urban and industrial areas subtly oppress rural

communities by scapegoating them and manipulating them into dependence under the guise of modernity. Consequently, rural communities rapidly lose their identity as they adopt practices that they perceive to indicate progress at the expense of their traditional lifestyles, cultures and use of their indigenous knowledge. Rejection of factors associated with their identity as rural citizens in sub-Saharan Africa ultimately affects their ability to withstand the adversity associated with hazard impact and disasters.

The intrusion of urban ideals and expectations has eroded the essence of livelihoods, ideologies and culture that ultimately constitute the underlying origins of rural coping strategies. Rural communities have historically acted as buffers for industrial areas by not only providing labour supply but also being located where key minerals are found and mined. This is in addition to continually acting as the dumping ground for activities in the industrialised and urban areas. This has and continues to impact on the resilience and progression of these communities because they are continually being battered with environmental degradation, socio-political turmoil and economic downturns (such as the land-grabbing phenomenon). What is interesting and of importance is to differentiate between vulnerability stemming from external or urban origins and those stemming from local factors. This is significant, as it will help to inform the way forward in dealing with sub-Saharan vulnerability.

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CHAPTER 16

Conclusion

Considerations for the Future

Genene Mulugeta and Thokozani Simelane

Africa is a continent that is prone to a wide variety of natural and human-induced hazards and disasters. Hazards such as droughts, floods, storms, earthquakes and volcanoes, wildfires, epidemics, and air and water pollution cause extensive losses to livelihoods and property. These losses aggravate poverty in most parts of Africa. They lead to the reversal of development gains and to increased impoverishment. The poor are consistently the most affected.

The population of Africa, estimated at one billion in 2012, is increasing at a rate of two to four per cent per annum, which means that the number of people exposed to natural hazards and disasters will continue to rise. Additional contributory factors to Africa's high vulnerability to disasters include displacement due to ongoing wars, economic hardships, high rate of population growth, food insecurity, inappropriate use of natural resources, and failures of policy and institutional frameworks. Despite the huge negative impacts of natural and human-induced hazards on Africa's development, little has been done to prevent these hazards. The reduction of disaster risks through preventative measures needs to be a central concern for the development of the continent. However, the political will and financial resources required for effective disaster reduction are often inadequate.

The cumulative effects of these disasters lead to lack of economic growth and prosperity in Africa. In addition, the complex ongoing processes of climate change, resource depletion and globalisation exacerbate the effects of hazards and disasters. The impact of disasters is particularly challenging for Africa's development agenda, given that 33 of the 49 least developed countries are located in Africa. These countries are the most vulnerable to global environmental change and lack the necessary human, institutional and economic capacity to cope with the impacts of disasters and hazards.

Recognising the adverse effects of human-induced hazards and disasters, African scientists participating in the International Council for Science, Regional Office for Africa (ICSU-ROA) Hazards and Disasters Program sought to develop a science plan and research activities for the understanding and assessment of disaster threats in Africa. One of the proposed initiatives was producing this textbook on natural

and human-induced hazards and disasters in Africa. A team of African scientists have contributed their expertise to bring together a broad range of subjects on hazards and disasters in this book. These subjects are divided into four parts and aim to explain the causes and consequences of hazards and disasters in Africa. Part I presents a general overview and provides statistical information on natural and human-induced hazards and disasters that have an impact on Africa. In Part II, the various geophysical hazards that affect Africa are discussed. The major geophysical hazards that impact Africa include: seismic, volcanic and landslide hazards. Seismic and volcanic hazards are concentrated along the East African Rift System and the Cameroon Volcanic Line, and also occur in northern Africa, where seismicity and volcanism are more broadly distributed. By comparison, landslide hazards are pervasive and impact almost all parts of the continent. Part III takes up the impact of climate change and hydro-meteorological hazards on the continent. Africa's disaster profile is almost totally dominated by hydro-meteorological hazards such as drought, flooding and storms. These are forecast to increase in frequency and magnitude due to climate change.

It is now widely recognised that a changing climate is putting stress on the Earth's system and human well-being through its effect on agricultural, marine and fresh water systems. It is therefore urgent that the necessary adaptation and mitigation measures are taken to reduce the risks. Part IV looks at Africa's vulnerability to disasters, mainly focusing on aspects of urban, rural and coastal vulnerabilities. More than ever, new ideas and strategies are needed to deal with Africa's vulnerability/sustainability challenges. Awareness is also growing that vulnerability to disasters must be at the core of fighting poverty, as the poor are the most affected by and most at risk from natural and human-induced environmental hazards and disasters.

As outlined in this book, Africa is vulnerable to a wide range of natural and human-induced hazards and disasters. In consequence, human and material losses continue to increase. These are made worse by weak governance, recurrent conflicts and unsustainable development practices in most of Africa. Africa's disaster profile is characterised by large-scale and numerous smaller-scale recurrent disasters. While the major disasters attract the attention of the media, the smaller ones remain largely undocumented and unreported, especially as concerns poor households. Whereas the main responsibility for averting hazards from becoming disasters lies with decision- and policy makers, it is the task of academics to provide science-based solutions that address the challenges posed by natural and human-induced hazards and disasters.

For most countries in Africa, there are gaps in the availability and quality of scientific data and information, and where quality data and information are available they are often not sufficiently used and shared. However, any effective strategies to prevent hazards from developing into disasters require not only knowledge generation and application but also effective policies. The future course in dealing with human-induced hazards and disasters should be to provide answers on how scientists

can assist policy makers to make informed decisions for reducing disaster risks. It is also necessary to work out how best to ensure that the results of scientific findings are incorporated into policies. The practical conclusion that can be drawn from the examples provided in this book is that local communities need to be informed so that they can be better prepared for future disasters and hazards.

Natural and Human-Induced Hazards and Disasters in Africa

Natural and human-induced environmental hazards are becoming increasingly prominent. The frequency of recorded natural disasters rose markedly during the last century, from about 100 per in the years up to 1940 to nearly 2 800 during the 1990s. Africa is the only continent whose share of reported disasters has increased over the past decade. Several factors contribute to Africa's high vulnerability to disasters. These include the high rate of population growth, food insecurity, high levels of poverty, inappropriate use of natural resources, and failures of policy and institutional frameworks. Despite the huge negative impact of natural and human-induced hazards on Africa's development, little is done to prevent them. Disaster prevention contributes to lasting improvement in safety and sustainable livelihoods and is essential as part of integrated disaster management strategies. The provision of effective scientific input to policy formulation on various issues related to hazards and disasters is an ambitious undertaking. It requires the collaborative effort of the African scientific community to develop comprehensive long-term strategies and human capacity-building initiatives that will enable science to benefit society. This will further require:

- a) Building strong research and training institutions in Africa at national and regional levels;
- b) Facilitating the exchange of scientific information and sharing of ideas across borders;
- c) Strengthening the link between scientific research and policy making;
- d) Promoting outreach activities to build resilience to disaster risk; and
- e) Tapping the knowledge base of rural and urban communities.

In this volume, the ICSU ROA has brought together selected African scientific researchers to share their views on policy direction for facing challenges linked to natural and human-induced hazards. The book is intended for policy advisers, environmental scientists, government officials and members of the general public with a special interest in environmental issues.

About the Editors

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